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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled SENSORY MODALITY MATCHING AND MATHEMATICS EDUCATION submitted by Reo Elden Ganson in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Elementary Education.

ABSTRACT

The purposes of this study were (1) to extend the testing of Sensory Modality Matching (SMM) tests (visual, auditory and haptic), as developed by Jarman (1975) and Sawada and Jarman (in press); of selected cognitive process tests (trail-making, figure copying, digit span and subitization) as developed by Das, Kirby and Jarman (1978); and of scholastic achievement tests (reading comprehension, reading decoding and mathematics achievement) as developed by the local school district: (2) to study the specific haptic sensing strategies and the relationship these strategies may have with students' mathematics performance of grade one students. The SMM tasks each consisted of a linear stimulus pattern followed by a linear comparison pattern which the student deemed as being the "same" or "different".

Two samples were selected, Sample 1 consisting of 90 grade one students selected from suburban elementary schools and Sample 2, a subset of Sample 1, consisting of 22 students. Sample 1 was tested using the SMM tests, cognitive process tests and achievement tests, while Sample 2 students had their haptic sensing strategies studied in depth.

The data obtained, were organized by correlation analysis and factor analytic techniques to reveal both the performance levels and the types of information processing that were characteristic of grade one students (Sample 1). Initial haptic sensing strategies were identified during the subjects' performance on the haptic-haptic SMM tasks. Alterations were also noted as the subjects continued through the five SMM tests (Sample 2).

It was found that planning strategies had a positive correlation on individual mathematics performance. Simultaneous and successive snythesis, invariant types of information processing, were not major factors used by the subjects when performing SMM tasks.

The major finding of this study is the subjects' use of planning as determined in the analysis of the haptic sensing strategies. Students who were able to plan specific strategy changes during the SMM tasks consistently improved their mathematics performance while those who were unable to utilize planning performed to a level equal to or below chance.

This finding has major implications for mathematics educators in the lower elementary grades. The emphasis of mathematics education needs to focus on the development of strategies and planning skills utilized by students. This may be best be accomplished through the frequent use of conventional and novel problem solving experiences. Students should experience such activities in order to effectively develop strategy and planning skills.

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To God, who gives strength to make all things possible.

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CHAPTER 1

INTRODUCTION TO THE STUDY

A series of recent research projects studied the relationship between Sensory Modality Matching (SMM) skills and cognitive processing. Jarman (1975) studied in detail the relationships between intelligence (low IQ, normal IQ, high IQ) and the information processing ability of 180 grade four males. As part of the study, the subjects were given SMM tests, within and between the visual and auditory modes. Each subject was first presented with a stimulus in one modality which was then removed. A comparison stimulus was then presented in a matching or nonmatching modality. The subject was to determine if the comparison stimulus was the "same" as or "different" from the initial stimulus. Each stimulus in the visual modality was presented as a linear array of dots having either short or long gaps between them. The auditory stimulus consisted of a series of beeps played on an audio-recorder with short or long pauses between the beeps. A more detailed discussion of the stimuli is found later in this study. From this study, Jarman concluded that "IQ groups differ in their planning and decisions regarding an appropriate strategy for cognitive tasks".

In a later report, Jarman (1978) gave further support to his earlier findings. He claimed that subjects' performance in auditory and visual matching tests also varied directly with the level of IQ (low, medium, high) and when considered across these three IQ groups, differential factor patterns appeared and/or disappeared entirely. These factor patterns or strategies were identified as (a) rehearsal and

retrieval processes and (b) verbal coding processes. It was found that the high IQ group mainly used verbal coding while the low IQ group relied primarily on the processes of rehearsal and retrieval. The medium IQ subjects employed a combination of both factor patterns. Two questions here remain unanswered: (1) what were the subjects rehearsing or coding, and (2) would younger subjects (grade 1) reveal similar factor patterns?

Sawada and Jarman (in press) in testing grade 3 subjects (male and female) added a parallel constructed haptic modality test to the auditory and visual modality tests developed by Jarman (1975). By correlating subjects' performance on these SMM tests with mathematics achievement (measured by a locally prepared mathematics achievement test) they determined that the matching strategies involving the haptic modality were more highly correlated to mathematics achievement than were the matching strategies involving the visual and auditory modalities. Subjects' haptic matching strategies were also found "to be more strongly related to mathematics achievement than to either reading decoding or reading comprehension (as tested by standardized reading tests)".

No attempt was made to identify what specific strategies the subjects used to encode, store, decode and match the two stimuli. Are similar strategies being used in each of the three modalities? If subjects did encode each linear stimulus to a series of digits, as suggested by Jarman (1975), what implications arise that relate to the capacity of the short-term memory (STM) store (Miller, 1956)? Does a relationship exist between the findings of Jarman and early number concepts (Fuson, 1977 Draft Paper) as taught in elementary mathematics

programs? Furthermore, if haptic modality matching performance is correlated with mathematics achievement at the grade three-four level does the same correlation exist at the grade one level? If so, what implications are there for the use of manipulative materials in teaching elementary school mathematics? What implications exist for the teaching of strategies to lower elementary students?

STATEMENT OF THE PROBLEM

This research is designed to have two major purposes:

1. To determine the performance level of grade one students on various Sensory Modality Matching tasks, related cognitive process tasks and their scholastic achievement, and to discover interrelationships in students' performances on the above tests.

When grade one children receive a sensory modality matching (SMM) stimulus, as used by Jarman (1975) and Sawada (in press), and match it with a SMM comparison stimulus, is their performance similar to that of grades three and four students? Is it possible that young students are able to develop various haptic strategies? Do these systems vary over intra-modal and cross-modal tasks? Are children able to adjust and change a matching system when they desire? This study is designed to compare the performance of grade one students in various SMM tasks and related cognitive process tasks of successive processing, simultaneous processing and planning. Further analysis will study the extent to which these abilities relate to achievement in the scholastic areas of mathematics and reading. The final aspect of this purpose will establish relationships, if any, the results of

this study have to those of other related studies.

2. To study various haptic sensing strategies used by students on SMM tasks and the relationship these strategies may have with the students' mathematics performance.

What role do various haptic sensing strategies have on a student's individual performance on SMM tasks? Is a student's ability in mathematics a reliable factor to predict specific haptic sensing strategies or is the converse true? Observational and statistical analysis will be used to study the various haptic sensing strategies of grade one students when performing SMM tasks and attempt to relate these to the students' mathematical ability.

DEFINITION OF TERMS

For the purpose of this study, the following terms will used as defined.

Chunking: the process of combining "single stimuli into larger units" (Klatzky, 1975) as related to STM. The number of units which can be chunked together is seven plus or minus two, (Miller, 1956) with a unit having variable size (eg. word, letter, or syllable).

Coding: the total sum of the cognitive processes necessary for the receiving and storage of stimulus traces. Das et al (1979) states, "coding, broadly considered, represents input, recoding, and storage of information".

Cross-modal Matching: the matching of a stimulus pattern in one modality with a comparison pattern presented in

a differing modality.

Decoding: the retrieval and recoding of stored information for use in decision-making.

Encoding: the coding process dealing with the recoding of input stimuli for storage.

Intra-modal Matching: the matching a stimulus pattern in one modality with a comparison pattern presented in the same modality.

Inverse Scoring: the system of scoring in which a high score indicates a poorer performance than a low score.

Planning: the ability to establish and alter schemes for problem solving.

Problem: a situation in which a student cannot readily find a solution.

Problem Solving: the process by which a satisfactory solution is found to a problem.

Subitization: the immediate apprehension of a number of objects in a set. It is reported that for young children subitizing occurs only for numbers less than five (Klahr and Wallace, 1976).

ORGANIZATION OF THE REPORT

Chapter 1 contains the overall and the specific statement of the problems to be studied. A general review of related research is contained in Chapter 2. Chapter 3 contains a detailed description of the selection of the sample, development and selection of the tests, experimental design, research procedures, and the collection and

recording of data. Chapter 4 presents a discussion resulting from the statistical analysis of the data. The fifth chapter contains detailed study of the haptic sensing strategies of the subjects. Chapter 6 includes a discussion of the conclusions, implications and suggestions for further research.

CHAPTER II

BACKGROUND TO THE STUDY

The present study, as discussed earlier, is in part a replication and an extension of earlier studies: Jarman (1975), Sawada and Jarman (in press) and Sawada (in press). Extensive summaries of related research are readily available in the above mentioned studies. These studies, however, raised certain questions pertaining to the performance of middle-elementary grade subjects on intra-modal and cross-modal sensory matching tasks, questions which are addressed below under three headings: information processing, short-term memory and haptic sensing maneuvers.

Information Processing

The cognitive abilities of humans have been the focus of much psychological research since Spearman (1927) postulated his "g" as a physiological source for man's reasoning powers. Recently, Das, Kirby and Jarman (1975, 1979) designed a model for human cognitive abilities. Their proposed model of information integration included simultaneous and successive processes.

Das, et al (1975) referred to simultaneous information processing as a "synthesis of separate elements into groups, these groups often taking on spatial overtones". This then is the processing of any part of a whole which is perceived instantaneously with disregard to its position in relation to the whole. In contrast, "successive information processing refers to processing of information in a serial order." The

distinctive difference is the inability to process a total result at a given moment in time. Luria (1966 a, 1966 b) has identified three processes within each of simultaneous and successive synthesis: That of perceptual, mnestic (memory) and complex intellectual conceptual cognitive operations. Das has incorporated these into his model. A more generalized description of these processes is given by Das and associates (1975, 1979).

Further, in studying the model, one assumes that the individual can select either or both modes of processing as determined by habit and tasks demands. Both simultaneous and successive processing can be involved in all forms of information processing.

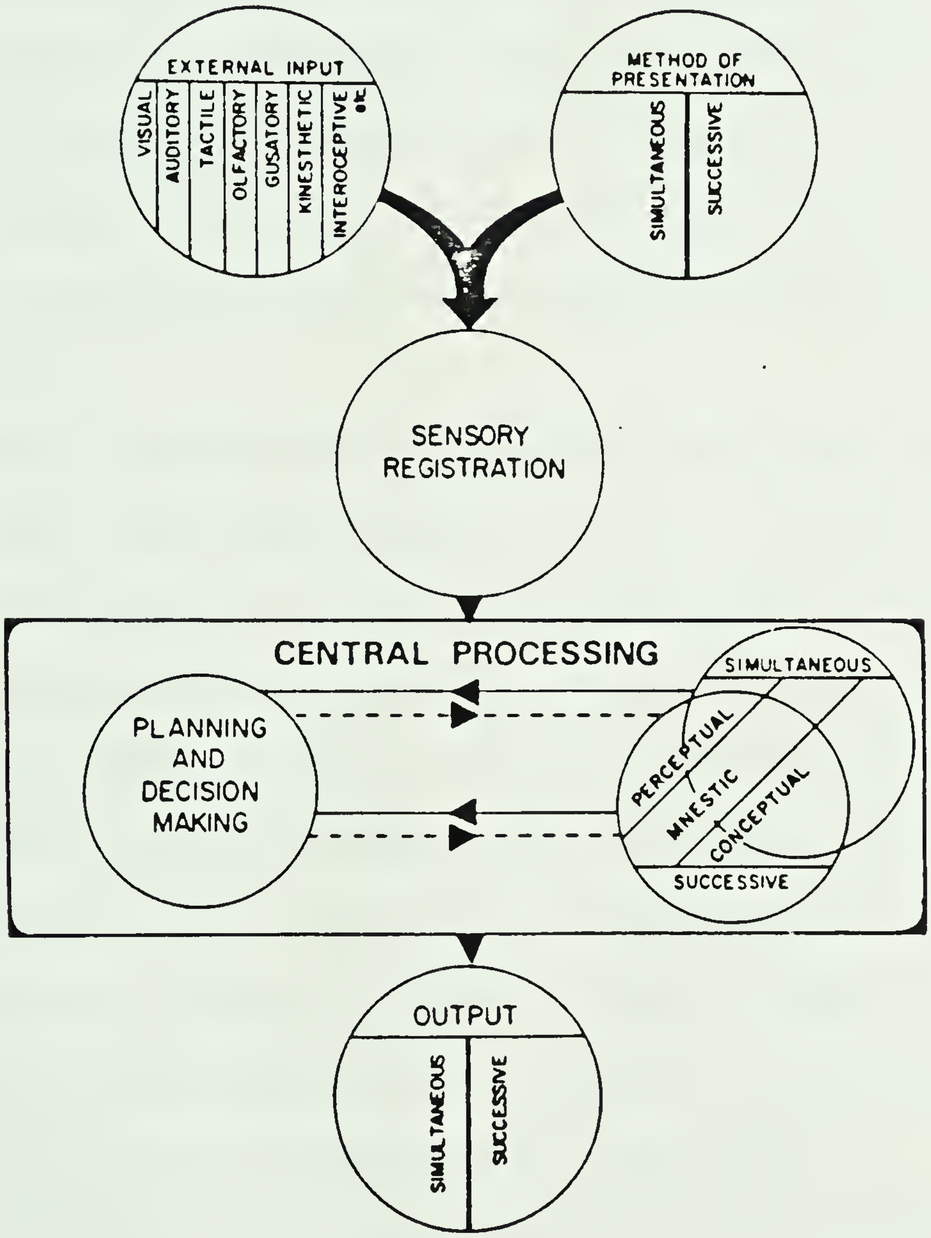
It is therefore conjectured that in processing information, external stimuli (input) are received through the varied senses including the visual, auditory and haptic modalities. These stimulus traces or memory traces, which are either short-term or long-term are integrated in a sensory registry. A transmission is then made to central processing where simultaneous and/or successive synthesizing takes place. A response (output) is now formulated which determines and organizes individual performance or behavior.

A diagram of the above components is included so the reader may more clearly follow the path of a stimulus from input to output. (See Diagram 1).

Two specific cognitive techniques were noted by Jarman (1975) as individually related to the auditory and visual modalities. The first technique was direct recall of tone sequences. This was primarily demonstrated with the A-A (auditory-auditory) matching tasks for the low IQ group. The second strategy was numerical coding. Jarman found

DIAGRAM 1

Information Integration Model



Das, J.P., Kirby, John R. & Jarman, Ronald F.

Simultaneous and Successive Cognitive Processes, 1979.

that this strategy was dominantly used on all intra-modal visual tasks. Then adding a parallel haptic dimension, Sawada (1979) also identified varied haptic sensing strategies and techniques used by the subjects but only speculated to related cognitive processes. The haptic strategies were dominated by a left-to-right feeling of the individual beads. Although this was an expected strategy, the question of how this stimulus was encoded, stored, and then matched to the comparison stimulus needs to be considered. Were the students counting clusters of beads, or differentiating the spaces between the beads, or something altogether different? How did the actual matching happen? Is there a relationship between haptic strategy and the cognitive process being used?

Although the above research has identified some cognitive processes used in SMM, others remain unknown. In Jarman's study the two matching strategies are related to two modalities (auditory and visual). How these were used by the subjects for cross-modal matching is not clear. Using factor analysis Jarman concluded, however, that for the high IQ group, all information, visual and auditory, was encoded "to a common numerical code". What about the middle and low IQ groups? Was this done by the subjects in Sawada's study for haptic information? He identified, by observation, three varieties of numerical coding. These can be illustrated by considering the pattern "● ●   ●   ● ● ●" . One strategy was to cluster the dots and count the number in each group, such as, "2, 1, 3". A second technique was a variation of counting and pausing: "1 - 2, (pause) 3, (pause) 4 - 5 - 6". The third strategy consisted of the number of groups, such as "3 groups". Of the 24 observations, only 2 occurred on cross-modal matching tasks

Of the 24 observations, only 2 occurred on cross-modal matching tasks and 12 involved the haptic (H) mode. Twenty-two of 130 observations occurred during visual tasks. This supports Jarman's findings of the relationship between visual tasks and numerical coding.

Other strategies such as counting the spaces can be speculated. For the example above, the spaces between the dots may be referred to as "short - long - long - short - short". This parallels an application of the once widely used Morse Code of "dit - da - da- dit - dit". This strategy however is highly unlikely to occur due to lack of exposure to Morse Code in the child's environment although some variations may be present.

A child's early number experiences may also be closely related to the specific strategy employed. Does counting actually occur in all cases or do the students use subitizing techniques? When matching the shorter linear patterns (3 dots and 4 dots) is the strategy used the same as that used when matching the longer linear patterns (5 dots to 8 dots)? Do individuals use the same strategy for a visual-auditory (V-A) task as he does for a A-V task? For a H-A task? Or for an A-A task? Is it possible that for the shorter tasks no encoding strategy is used at all and subjects simply determine "same" or "different" through congruence or incongruence of the perceived patterns?

Short-term Memory

The notion that memory consists of two distinct kinds, namely short-term memory (STM) and long-term memory (LTM), dates back to the turn of the century (Muller & Pilzecker, 1900). Hergenhahn (1976) stated that "short-term memory is triggered by sensory stimulation and

continues for some time after the stimulation has ceased. Exactly how long the activity continues is not known, but it seems that the information stored in short-term memory is available for less than a minute" (p. 329).

Peterson and Peterson (1959) determined that the best retention interval for immediate recall (STM) was three seconds with the period three to six seconds next best. In the SMM tests used by Jarman and by Sawada, the time interval between the initial stimulus and the comparison stimulus did not exceed five seconds. Therefore it seems evident that subjects needed to rely only on their STM and related strategies during these studies. However, there is no indication that this is in fact the case or if the STM strategies of chunking and rehearsal were used by the subjects.

Miller (1956) determined the magical number seven (plus or minus two) to be the average number of "bits" of information to be processed at a given time by average individuals. In order to increase the number of specific items which can be absorbed into memory, certain strategies have been found to be useful. "Chunking" (Miller, 1956) or "clustering" (Bousfield, 1953) is a technique whereby single stimuli are combined into larger units. These units contain more or less information as circumstances permit. A second strategy is referred to as "rehearsal" (Helleyer, 1962, Adams, 1967; Posner, 1967; Klatzky, 1971). In studies involving STM and rehearsal, subjects are instructed to repeat the stimulus either aloud (overt practice) or silently (covert practice) and then recall the item after a given period of time. Helleyer and Klatzky found that rehearsal does increase recall in STM. Adams argues that the reason for such findings is that

practice increases resistance to forgetting by slowing down the rate of decay rather than delaying the onset of decay. In either case, the recall of information from STM memory is more functional with the use of rehearsal.

Low IQ (below 80) has been thought to be highly related to a poor STM (Galton, 1968; Jensen, 1964; Ellis, 1963; Brown, 1974). Although this point has been disputed by Wechsler (1949) it is generally believed that STM is closely connected to intelligence. This conclusion may explain why the low IQ groups within a normal population in the studies conducted by Jarman and by Sawada performed most poorly on the SMM tests and the high IQ groups performed best. Can it be concluded that similar results would be obtained having younger children as subjects?

Haptic Sensing Strategies

Sawada (1979 b) observed the haptic sensing strategies used by subjects during SMM tasks involving the haptic modality. He identified the most consistent pattern as well as common deviations. A left-to-right technique of feeling each bead was used by 73% of the 160 subjects. This is not surprising for two reasons. Firstly, the left-to-right pattern of visual sensing has been firmly founded because of the reading program. Secondly, an auditory stimulus was presented in a manner such that the beginning of the auditory signal corresponded to the left side of the visual representation of the stimulus and proceeded across the pattern to end the signal at the right of the visual representation.

Another 20% of the sample used a right-to-left technique. This technique raises several questions. Did these subjects also reverse the visual and auditory patterns or did reversal happen only in connection to the haptic stimuli? Did reversal take place during the perception stage or during processing? In encoding the initial stimulus, what role if any did the STM facilitators of chunking (Miller, 1956) and rehearsal (Klatzky, 1975) have?

Fuson (1977, Draft Paper) reported a study by Bell, Fuson and Lesh (1976) focusing on the development of early number concepts in children. Two items of interest were cited as relating to the number word system and the number symbol system.

1. The values of given digits are explicitly named and these names are read from left-to-right. eg: five thousand six hundred ten.
2. The number symbols are learned, beginning with digits and position (place value) and the main relation moves from right-to-left. eg: the increasing of size from units to tens to hundreds etc.

In this grade level (grade 3 - 4) a great deal of emphasis in the mathematics program is also placed on the sequencing of the basic algorithms of addition and subtraction. These algorithms also largely depend on a right-to-left movement.

Since Sawada found a significant relationship between the subjects' performance on the haptic SMM tasks and mathematics achievement, could it be that the right-to-left sensing movement is related to the development of mathematical concepts?

Other haptic sensing strategies, identified in the remaining 7%

of the sample, were feeling all the beads simultaneously with a finger spread or feeling the beads quickly back and forth without feeling individual beads. Do these specific haptic strategies give an indication of the cognitive processes being used by the subjects? Is there a relationship between mathematics achievement, reading achievement and haptic sensing strategies? These questions still need to be considered.

CHAPTER III

STUDY DESIGN

The design of the study consisted of the selection of a sample, development and selection of tests and procedures, the administration of appropriate tests, and the collection and recording of the data and observed behaviors. Each of these components is discussed in the sections which follow.

DESCRIPTION AND SELECTION OF THE SAMPLES

Participants in the study were selected from eight grade one classrooms in three elementary schools. The schools were located in various newly developed areas of metropolitan Edmonton. Due to these locations the schools' enrollment came largely from families having recently relocated into new homes and new communities.

There were two samples selected, one being a subset of the other. The larger sample, noted herafter as Sample 1, consisted of 96 students, 32 from each school. The students were randomly selected from the total grade one population in each school. There was no attempt made to control the selection in regards to sex, intelligence, age or school achievement. The smaller sample, noted hereafter as Sample 2, consisted of 24 students, 8 from each school. They were selected to serve as subjects for the observational study into specific haptic strategies. This selection took place during the first testing session. The 32 students (Sample 1) from each school were

randomly assigned to groups of four subjects and given the H-H modality matching test. The haptic sensing strategies of each student were observed and recorded. After all students were tested on the H-H task, eight from each school were selected on the basis of varied haptic sensing strategies. Students were then reassigned within the groups of four subjects to allow one and only one of the Sample 2 students in each group. This made possible the opportunity to video-tape record the haptic maneuvers of the selected subjects during each of the following tests. The data collected on these 24 students will be discussed in detail in Chapter 5.

THE TESTING INSTRUMENTS

The twelve tests used with Sample 1 in this study are grouped into three categories as related to their function. These functions are:

1. scholastic achievement;
2. modality matching;
3. cognitive processing.

Scholastic Achievement Tests

The achievement tests used were locally developed by the Edmonton Public School Board to reflect curriculum changes in their school programs.

Elementary Reading Test

The Elementary Reading Test was designed to be administered in three sittings, each of approximately one hour. Of the 100 questions asked, 50 questions tested word decoding and 50 questions tested reading comprehension. The Word Decoding section was designed to assess the following four basic decoding skills. (1) Sight words: to recognize instantly words that occur frequently in word lists. (2) Contextual analysis: to anticipate and identify words by using syntactic cues, by using no-point cues and by using semantic cues. (3) Phonic Analysis: to associate phonic symbols with corresponding speech sounds using single consonants, using two or three letter digraphs in initial, final and medial positions, using single vowels and using phonograms. (4) Structural Analysis: to associate sounds and meanings of structural elements within words with their corresponding graphic symbols using word structures and using word endings (Test Manual).

The Reading Comprehension section was designed to assess achievement as determined by the following objectives. (1) Vocabulary: To increase and enrich vocabulary through discussions of real experiences, print and non-print materials. Develop and label concepts for describing real and imaginary animals, people, objects, places and happenings. Understand the use of connectives to establish word relationships. Establish depth and breadth of word meanings in phrase and sentence structures. (2) Literal comprehension: To locate and/or recall detail in pictorial and printed materials, the sequence or order of events or objects, main ideas and subordinate ideas,

relationships among objects, patterns, words and ideas. (3) Inferential comprehension: To infer relevant details, the sequence or order of events or objects, predictions, conclusions. (4) Critical comprehension: To evaluate and/or judge ideas by detecting that which is absurd or plausible, is realistic or imaginary, is true or false (Test Manual).

The validity of the test was determined by the expert judgment of committees of elementary teachers and consultants who constructed the test. Study was given to determine the content validity of the test items against the before mentioned concepts and it was determined to be valid.

The reliability coefficient was determined through the use of Kuder-Richardson 20 formula. On a scale range from 0 to 1, the reliability coefficient was 0.945.

Elementary Mathematics Survey Test (Revised Edition)

The Elementary Mathematics Survey Test was designed to be administered in two sittings, each of approximately 40 minutes. The test consisted of a total of 60 questions, testing the following seven basic mathematic skill areas. (1) Associate objects with numerals 0-9: identify two equivalent sets or sets with more or fewer members by placing members of a set in one to one correspondence. Associate a set of objects with a numeral 0 through 9. Read, write and order numerals 0 through 9. (2) Geometry: classify according to surfaces and shapes: cones, cylinders, spheres and polyhedra. Identify and classify according to shape 2-D drawings of triangles, squares, rectangles and circles. Match a 3-D shape with the 2-D representation

of that shape. (3) Addition and subtraction processes, story problems: identify the processes of addition and subtraction. Solve oral story problems involving one complete basic fact sentence. (4) Non-standard measurement: Compare lengths of two or more objects using terms such as "longer than", "shorter than", etc. Find the approximate length of a given object using non-standard units of measure. Compare masses of two or more objects using terms such as "heavier than", "lighter than", etc. Compare capacities of two or more containers using terms such as "more than", "less than", etc. Observe the differences in temperature using the terminology hot, warm, cool and cold (senses only). (5) Basic facts to 9: Master the basic facts of addition and subtraction with sums and minuends through 9. (6) Two-digit numeration, fractions, ordinals: develop place value concepts through two digits. Read, write and order numerals 0 through 99. Identify the fractions 1/2, 1/4 and 1/3. Use ordinals through tenths. (7) Time, calendar, money: tell time to the hour. Know the days of the week in order. Recognize and state the singular value of the one dollar bill and the one cent, five cent, ten cent, twenty-five cent and fifty cent coins.

Test validity and reliability were determined in a similar manner as that of the Elementary Reading Test. The content validity was found to be high and the reliability coefficient was 0.88.

Modality Matching Tests

Five modality matching tests were used. The tests were developed and reported by Jarman (1975) and Sawada and Jarman (in press): (1) haptic-haptic (H-H), (2) haptic-visual (H-V), (3) visual-haptic (V-H),

(4) haptic-auditory (H-A) and (5) auditory-haptic (A-H).

Each test consisted of 31 items. The first five were used for practice. The same stimulus patterns were contained in all five tests. See Appendix A for stimulus patterns. Each pattern was composed of a linear array of stimuli, for example, the variations of four components include.

(a) ●   ●   ●●

(b) ●   ●●   ●

(c) ●●   ●●

(d) ●   ●   ●   ● .

The number of components in each stimulus array varied from three to eight. However, no item occurred where the number of components contained in the stimulus item was different from the number of components in the comparison item.

Haptic patterns These patterns were produced from round headed map tack pins pressed into rectangular wooden rods. The diameter of the head was 4 mm, short gaps were 3.5 mm and long gaps were 16 mm.

Visual patterns Visual patterns were produced as a linear sequence of dots with variation created by short gaps and long gaps. In a pattern where a dot had a diameter of one unit, short gaps were 0.80 units and long gaps were 7.17 units. The patterns were photographed onto slides and the speed at which they were projected was controlled by impulses recorded on an audio-tape. The projection time of each slide varied proportionately with the length of the item.

Auditory patterns Auditory patterns were produced as

sequences of tones recorded on an audio-tape. The tones were created by recording a sound frequency of 1000 cycles per second for a duration of 0.15 seconds. Variations in patterns were created by short pauses of 0.35 seconds and long pauses of 1.35 seconds. The patterns were each recorded using a left to right sequence.

In each test, an initial pattern (stimulus) was presented in one modality (haptic, visual or auditory) and the student was to judge if it was the "same" as or "different" from a subsequent pattern (comparison) presented in the matching or nonmatching modality. Thus any item having no difference between the stimulus and the comparison patterns was scored as "same".

Example: Stimulus pattern

● ●   ● ●   ●

Comparison pattern

● ●   ● ●   ●

An item having a correct answer of "different" could have a difference in the comparison pattern at any point throughout the pattern.

Example: Stimulus pattern

● ● ●   ● ●

Comparison pattern

● ● ● ●   ●

or: Stimulus pattern

● ● ●   ● ●

Comparison pattern

After each comparison pattern the student circled "same" or "different" on the answer sheet provided. All responses were scored zero for incorrect and one for correct. No correction factors were used for possible guessing.

Since all tests had been previously tested (Jarman, 1975; Sawada and Jarman, in press) no revisions were considered necessary. The introductory instructions, timing sequence and script for each test is included separately in Appendix A.

<u>Haptic-Haptic Matching Test</u>

A console was used (See Appendix A) which allowed the testing of four students per sitting. Both the stimulus and comparison patterns were presented to the subjects in the haptic mode.

<u>Haptic-Visual Matching Test</u>

This test involved the matching of a haptic stimulus pattern with a visual comparison pattern. The visual pattern was projected through a Singer Caramate at eye level of the students.

<u>Visual-Haptic Matching Test</u>

The items in this test were converse of the items in the haptic-visual matching test, the visual representation being the stimulus pattern and the comparison portion being the pattern of beads to feel.

Haptic-Auditory Matching Test

Each item in this test was comprised of a haptic stimulus followed by an auditory comparison. The auditory patterns were produced by playing a prerecorded audio-tape on a cassette recorder at a loudness level of a person normally talking in the room.

Auditory-Haptic Matching Test

This test was the converse of the haptic-auditory matching test. The auditory set of tones was the stimulus half and the series of beads was the comparison half.

Cognitive Processing Tests

Three sensory processing tests were selected and one sensory processing test was developed. These tests have been found to indicate simultaneous and successive syntheses, planning schemes, short-term memory and chunking (Das, Kriby and Jarman, 1978).

Figure Copying

The figure copying test used was a modified form of one developed by the Gevell Institute (Ilg & Ames, 1964). The test consisted of four 2-D geometrical figures and six 3-D geometrical figures. Each subject was to reproduce by drawing, each figure (top half of page) directly under it (lower half of page). Each item has a maximum score of two, with a test total of 20. Scores per

item were awarded as 0, 1 or 2 according to the correctness of the reproduction. The figures consisted of a triangle, a rectangle with intersecting diagonals and midlines, a diamond in which the length is 1.7 times the height, a diamond in which the height is 1.7 times the length, a cylinder, two cubes in different perspectives, a rectangular right prism, an irregular prism having one pair of sides as isosceles trapezoids and hexagonal right prism. Copies of the 10 figures in the test and guidelines for administering and scoring the test are in Appendix B. The test was selected because success in this test seems to be related to the ability of a subject to envision the figure as a whole (simultaneous process), as supported by Das, Kirby and Jarman (1979). Since no time limit was placed upon the completion of the test, a subject could repeatedly reconsider the total figure during the reproduction process.

Digit Span Test

The digit span test was selected to measure short-term memory. The test consisted of 14 series of digits paired as to difficulty level. The examiner read a series of digits which was to be repeated by the subject by memory. The first two series each consisted of just two digits while the last two series consisted of eight digits each. The examiner read the digits at a rate of approximately one digit per second. The subject could begin repeating immediately after each series was read. Each subject was expected to repeat only one series at any one level correct before being given a longer series. A

subject's score was recorded as the longest number of digits repeated correctly. A copy of the digit span series is in Appendix C. Factor weightings of the Digit Span Test in several studies (Das, Kirby and Jarman, 1979) have indicated the test to be a measure of successive processing.

Trail Making Test (TMT)

The Trail Making Test orginated as part of the Army Individual Test of General Mental Ability (1944). It was adopted (Armitage, 1946; Reitan, 1955; Spreen and Gaddes, 1969; Das, 1981) to fulfill varied purposes. It was reported to measure planning and the ability to shift from one stimulus sequence to another. The TMT used was divided into Parts A and B. In Part A, the subject connected in correct numerical order encircled numbers (1-15) distributed randomly over page one. He then connected (on page two) in similar fashion, encircled numbers (1-25), the first 15 being in the precise position as those of page one. In Part B, the subject joined two sets of non-circled numbers having systematic patterns, one pattern for each of the two pages. Each subject was also given one sample page for practice.

Scoring was in seconds of elapsed time. In Part A, three timings were recorded: (1) total time for page one, (2) total time for page two, and (3) time difference between page one and page two. In Part B, four timings were recorded: (1) half-time of page one, (2) full-time of page one, (3) half-time of page two and (4) full-time of page two. A composite time was also recorded for each subject (The sum of all

four full-time readings). A test copy and administration directions are contained in Appendix D.

A subject's ability to perform well is reflected by a low score and a subject's inability to perform well is reflected by a high score on the TMT. This is often referred to as inverse scoring and will be referred to as such during the analysis of the data.

Subitization Test

This test was constructed by the experimenter. Klahr and Wallace (1976) determined that subitizing is a function of short-term memory and occurs during a simultaneous stimulus of five items or less. In the SMM items, the longest series of dots consisted of seven individual dots arranged in varying clusters. The longest cluster had four dots. The test consisted of a series of 15 linear arrays of dots, each portrayed on a 5x8 card. Arrays varied in lengths of 2 to 6 dots, each being shown three times. Item sequence was randomly arranged. Test items and directions for administration are contained in Appendix E. Each subject was given an answer sheet and a pencil to record the number of dots he saw in each array. Each subject was individually tested.

Summary List of Tests

The order of the above mentioned tests is summarized in Table 1 and this order will be maintained throughout the study for all references in reporting the data and analyzing the test results.

TABLE 1

TESTS USED IN STUDY

1. Reading Test: Word Decoding
2. Reading Test: Word Comprehension
3. Mathematics Test
4. Modality Matching Test: H-H
5. Modality Matching Test: V-H
6. Modality Matching Test: H-V
7. Modality Matching Test: A-H
8. Modality Matching Test: H-A
9. Trail-Making Test (Planning Strategy)
10. Figure Copying Test (Simultaneous Processing)
11. Digit Span Test (Successive Processing)
12. Subitization Test (Chunking Strategy)

PILOT STUDY

A pilot study was conducted just prior to the collecting of the data. The purposes of the pilot study were:

1. to familiarize the researcher with the hardware and procedures of the SMM testing. Since the items on the SMM tests were sequenced to an audio-tape, the ability to operate the testing hardware smoothly was essential. This was most important on the haptic tests as the stimuli were exchanged mechanically by the researcher.

2. to develop an interview protocol. Each subject in Sample 2 was to be interviewed after the third and fifth SMM test. This protocol, it was hoped, was to include questions which would not "lead" the child's thinking but to solicit from the subject the thinking patterns being used when matching the stimulus and comparison patterns.

3. to determine if grade one students could interact with the SMM tasks in a meaningful manner.

4. to assess if the prerecorded instructions of the SMM tests were sufficient for subjects at the grade one level. It was decided that if they were inadequate, additional instructional techniques would be developed and tested.

5. to determine the instructions necessary and the amount of time needed to teach the subjects how to score their answers on the SMM answer sheets.

6. to assess the discriminating value of the subitization test on grade one subjects. The test items were answered orally.

Ten grade one students were individually tested during the pilot

study. They were selected from an independent school in the same metropolitan area as that of the large samples.

Pilot Study Results

1. It was determined that to maintain a smooth operation of the testing hardware, an assistant was needed. This assistant would be responsible for coordinating the movement of students in and out of the testing area, the preparation of answer sheets and to assist in the administration of the cognitive process tests.

2. It was observed that a small percentage of the students could express their thinking when performing the SMM tasks (2 out of 10) but the majority could not. Because of this finding it was decided to abandon the planned interviews with the Sample 2 subjects.

3. Table 2 summarizes the SMM scores of the ten pilot study subjects and the corresponding SMM test. The SMM scores obtained do indicate that grade one students are able to perform SMM tasks at a level greater than chance. It was assumed that if the H-H, H-V and V-H tests could be performed so could the H-A and A-H tests.

4. The prerecorded instructions were found to be inadequate during the initial (H-H) test. An assortment of stimuli and response patterns were made (wooden strips, 1 cm by 30 cm, with identical patterns to the test items) and each subject was shown thes patterns. Time was provided for the subject to handle and feel the sequence. It was found that after this concrete experience the subjects were able to follow the recorded instructions. Once the first testing session was complete, no additional instructions were given.

TABLE 2

SUMMARY OF PILOT STUDY RESULTS

Subject	SMM Test	SMM Score	Subitization Score
1	H-H	14	5
2	H-H	21	5
3	H-H	11	4
4	H-H	22	4
5	H-V	19	5
6	H-V	20	6
7	H-V	15	3
8	V-H	16	4
9	V-H	19	5
10	V-H	11	4

5. All subjects readily understood the process of scoring their responses on the answer sheets by listening to the prerecorded instructions.

6. The subitization test scores are indicated in Table 2. The range of the scores was from 3 to 6. This seems to indicate a valid level of discrimination in the use of this test.

ADMINISTRATION OF THE INSTRUMENTS

The instruments were administered during May, 1980. The two Reading Tests and the Mathematics Test were administered by the school staff during the same time period. The scores for these instruments were obtained from the school principals at a later time.

A small reading room was provided for the administration of the SMM tests. Each group of four subjects was first given the H-H test. The remaining SMM tests were rearranged into 24 varying sequences as listed in Table 3 and each group was randomly assigned to a testing sequence.

Each of the four remaining tests was administered to all subjects individually. There was no attempt to establish a specified order of subjects during these tests. Subjects were tested according to availability.

Sample 2 subjects were not given any special attention during the writing of any of the 12 tests. The extra data relating to their haptic sensing strategies were collected through two means.

1. Careful notes were taken during each of the SMM tests by the examiner. Items of interest included hand movements during the haptic sensing, verbal clues of thinking processes and other behaviors relative to performing the SMM tasks.
2. A video camera was used to record the actual hand-finger movements during each of the four cross-modal SMM tests.

TABLE 3

TESTS SESSIONS PER GROUP

Group	TEST SESSIONS I	II		III	
A	H-H	H-V	H-A	V-H	A-H
B	H-H	H-V	H-A	A-H	V-H
C	H-H	H-V	V-H	H-A	A-H
D	H-H	H-V	V-H	A-H	H-A
E	H-H	H-V	A-H	V-H	H-A
F	H-H	H-V	A-H	H-A	V-H
G	H-H	H-A	H-V	V-H	A-H
H	H-H	H-A	H-V	A-H	V-H
I	H-H	H-A	V-H	H-V	A-H
J	H-H	H-A	V-H	A-H	H-V
K	H-H	H-A	A-H	H-V	V-H
L	H-H	H-A	A-H	V-H	H-V
M	H-H	V-H	H-V	H-A	A-H
N	H-H	V-H	H-V	A-H	H-A
O	H-H	V-H	H-A	H-V	A-H
P	H-H	V-H	H-A	A-H	H-V
Q	H-H	V-H	A-H	H-V	H-A
R	H-H	V-H	A-H	H-A	H-V
S	H-H	A-H	H-V	H-A	V-H
T	H-H	A-H	H-V	V-H	H-A
U	H-H	A-H	H-A	H-V	V-H
V	H-H	A-H	H-A	V-H	H-V
W	H-H	A-H	V-H	H-V	H-A
X	H-H	A-H	V-H	H-A	H-V

CHAPTER IV

RESULTS - PART 1

The first purpose of this study was to provide, in part, an extension to the studies of Jarman (1977), Sawada and Jarman (1978), Sawada and Perfrement (1982), and Sawada (in press) and Sawada and Jarman (in press). To support this purpose, the following discussion will include a descriptive summary of Sample 1, the data collected and the results of the analysis performed on the data.

The sample selected consisted of 96 grade one students consisting of 54 boys and 42 girls. Their ages ranged from 6 years 3 months (6-3) to 7 years 4 months (7-4) having a mean age of 6 years 10 months (6-10). Throughout the testing period, several students, due to absences from school, missed particular testing periods. Although an attempt was made to make up these tests, six subjects were deleted due to incomplete data.

AGE LEVEL ANALYSIS

The subjects were divided into three age groups, group 1 - low (6-3 to 6-6), group 2 - middle (6-7 to 6-10) and group 3 - high (6-11 to 7-4). The groups contained 27, 28 and 35 subjects respectively.

A total SMM score was obtained for each subject by adding together the five SMM test scores. The means and standard deviations for each group are given for each group in Table 4. Using analysis of variance these scores were tested to find if age played a signifi-

TABLE 4

AGE GROUP MEANS AND STANDARD DEVIATIONS

FOR TOTAL SMM SCORES

GROUP	MEAN	STANDARD DEVIATIONS
1 (n = 27)	68.58	12.73
2 (n = 28)	74.15	11.83
3 (n = 35)	81.44	12.55
TOTAL	74.86	13.10

cant role in the subjects' performance on these tests. The results are given in Table 5.

Some understanding can now be given to a question posed earlier in the purpose of the study, are grade one subjects able to consistently perform SMM tasks? It appears evident that the answer is a conditional yes. Groups 1 and 2 are both below the standard group mean of 74.86, however group two is only slightly below. As shown in Table 5, there is a strong significant difference between groups 1 and 3 ($P = 0.003$) and a weak difference between groups 2 and 3 ($P = 0.074$). A more careful look at the mean for group 1 ($\overline{X} = 68.58$), indicates that their performance is only slightly higher than chance (65). This observation, when considered with the limited age variance, seems to suggest two rather significant findings. First, the developmental stage present in students at this age. To find a significant difference between groups 1 and 3 when the age difference is limited (6-3 to 7-4, lower and upper limits) is critical when interpreting data later in the study. Second, the grade one student represents the youngest age subject, for whom this type of SMM task seems to be meaningful.

This study did not obtain IQ scores for the subjects due to an unexpected turn of events. During the pre data collecting period, the experimenter was informed by the school district that standardized IQ scores would be available from the school offices for the subjects. However, when the data were obtained for the standardized tests, it was indicated that the use of the IQ test was optional and two of these school did not administer the test, therefore no scores were available.

TABLE 5

DIFFERENCES BETWEEN AGE GROUPS

ON TOTAL SMM SCORES

GROUP	MEAN DIFFERENCE	PROBABILITY
1-2	-5.57	0.266
1-3	-12.86	0.003
2-3	-7.29	0.074

GENERAL FINDINGS

The data that were collected for the 12 variables for the 90 subjects are summarized in Table 6. Three observations are noteworthy.

The Ceiling Effect

The first point is the limited benefit received as a result of the ceiling effect present in the mathematics test scores and the reading decoding scores. The maximum scores were 60($\overline{X}$ = 56.22) and 50($\overline{X}$ = 45.14) respectively. Upon observation it should be noted that only 7 subjects recorded scores not within $\pm$ 1 standard deviation of the mean in mathematics and only 9 in reading decoding. As a result, no attempt was made to use either of these scores as a basis for determining varying achievement levels. The scores of the reading comprehension test were more varied, but without support from either of the other two achievement tests it was decided to not stratify the subjects into groups based on achievement levels.

Why was it that more variability was not obtained on the achievement tests? The answer to this question seems to relate to the major purpose these tests serve in the local educational program. That is, to measure mastery rather than ability. It becomes evident that the reading decoding test and the mathematics test are highly content structured, therefore the resultant limited spread in test scores.

Parallel Support for Cognitive Tests

The second observation supports the findings of the present study.

TABLE 6

MEANS AND STANDARD DEVIATIONS FOR THE TWELVE VARIABLES

VARIABLE TEST	MEAN n=90	STANDARD DEVIATION
1. Reading decoding	45.14	5.600
2. Reading comprehension	37.53	7.122
3. Mathematics achievement	56.22	4.22
4. Haptic-haptic matching	13.80	3.25
5. Visual-haptic matching	16.54	4.72
6. Haptic-visual matching	15.58	3.60
7. Auditory-haptic matching	14.60	3.12
8. Haptic-auditory matching	14.32	3.81
9. Trail-making	220.40	74.46
10. Figure copying	7.22	3.70
11. Digit span	4.60	1.05
12. Subitization	11.61	2.62

Molloy (1973) tested 60 grade ones on cross-modal (audio-visual tasks), figure copying and digit span as part of a study to determine the effects of age and socio-economic status on cognitive thinking patterns. He found that grade one students had a mean of 5.64 with a standard deviation of 1.33 on the figure copying test and a mean of 4.14 and a standard deviation of 0.73 on a digit span test. These results are similar to present results. The figure copying test has a mean of 4.60 and a standard deviation of 1.05. The figure copying tests were scored having a maximum score of 20 and the difference between the means of the two tests was 1.58. The digit span tests had a maximum score of 8 and the difference between the means is 0.46. The difference could easily be accounted for by the time of the year in which the tests were administered. Molloy administered his test during the middle of the school year while the present tests were given at the end of the year.

Parallel Support for SMM Tests

A third and major point in terms of the study is the relationship between the means of the present study and the means of 180 grade three subjects as found by Sawada (in press) on the SMM tests. A summary of these means as they relate to the five SMM tests administered to both samples is found in Table 7. The grade one sample had lower means on all five tests. When comparing the means, the V-H and the H-V tests were the best performed by both groups with V-H tests having the highest means. The means for the A-H and H-A tests are reversed for the two samples with only slight differences for the mean

TABLE 7

MEANS COMPARISON OF SMM TEST BETWEEN

GRADE ONE AND GRADE THREE SAMPLES

SMM TESTS	GRADE ONE MEANS n = 90	GRADE THREE MEANS n = 160
H-H	13.80	18.08
V-H	16.54	21.59
H-V	15.58	19.94
A-H	14.60	17.33
H-A	14.32	17.98

scores. The grade one sample scored consistently lower than did the grade three sample on the H-H test. This difference is assumed to be due in part to the different administrative sequence of tests for the two samples. All of the subjects in the grade one sample were given the H-H test first while this was not the case for the other sample.

CORRELATIONAL ANALYSIS

Expected Results

The results of intercorrelating the twelve variables (Table 8) give support to the findings of the before-mentioned related studies.

It was expected (Molloy, 1973; Jarman, 1975; Kirby & Das, 1977; Das, Kirby & Jarman, 1978; Ashman, 1978; Das & Jarman, 1981; Sawada, (in press) that the following relationships would be found to be significant.

1. Achievement tests to be related to each other.
2. SMM test results to be related to each other.
3. Cognitive synthesis tests (figure copying, trail-making, digit span) to be unrelated to each other.
4. Subitization to be related to figure copying, mathematics and reading decoding.
5. Figure copying to be related to reading comprehension and to mathematics achievement.
6. Digit span to be related to reading decoding.
7. Trail-making to be related to SMM tests.

TABLE 8

CORRELATIONS MATRIX FOR THE TWELVE VARIABLES

n = 90

VARIABLE TEST	1	2	3	4	5	6	7	8	9	10	11	12
1. Reading Decoding	---											
2. Reading Comprehension	77**	---										
3. Mathematics Achievement	59**	53**	---									
4. Haptic-haptic Matching	42**	35**	53**	---								
5. Visual-haptic Matching	36**	33**	49**	40**	---							
6. Haptic-visual Matching	21*	17	15	22*	45**	---						
7. Auditory-haptic Matching	23*	18	29**	14	40**	32**	---					
8. Haptic-auditory Matching	29**	26*	28**	25*	42**	49**	38**	---				
9. Trail-Making	-41**	-35**	-63**	-43**	-43**	-02	-19	-25*	---			
10. Figure Copying	33**	26*	27*	20	26*	37**	30**	28**	-17	---		
11. Digit Span	14	25*	19	06	11	01	03	-02	-22*	06	---	
12. Subitization	15	25*	06	19	20	23*	20	01	-04	29**	04	---

Decimal points omitted

*Significant at the 0.05 level ($r > 0.21$)

**Significant at the 0.01 level ($r > 0.27$)

8. Trail-making to be related to mathematics achievement.

Of these eight expectations, four are confirmed, (1,3,5,8) three are supported to varying degrees (2,4,7) and one was not confirmed (6).

FINDINGS AS RELATED TO EXPECTED RESULTS

Expectation 1. The three achievement tests: mathematics, reading decoding and reading comprehension are highly correlated (all correlations having $P < 0.01$). This supports the theory that mathematics achievement and general reading ability are indicators of similar cognitive processes.

Expectation 2. Of the ten correlations of the SMM tests, seven are significant at the 0.01 level, two are significant at the 0.05 level while one was found to be non-significant. This one involved the H-H test (intra-modal) with the A-H test (cross-modal). The two correlations at the 0.05 level of significance involved the H-H test (intra-modal) with the H-V and H-A tests (cross-modal). An interesting question is raised: Is there a different process involved when performing an intra-modal task than when performing a cross-modal task? These findings would suggest such was the case.

Expectation 3. The cognitive synthesis tests: figure copying, trail-making and digit span did not correlate with each other (all correlations having $P > 0.01$). Trail-making and digit span did, however, show a significant correlation at the 0.05 level. Das, Kirby and Jarman (1978) have shown that these tests weigh on three cognitive processes: namely, simultaneous processing, planning and successive processing respectively.

Expectation 4. Previous testing by Das, Kirby and Jarman (1978) indicates that simultaneous processing is important to results in figure copying, mathematics and reading decoding. With the use of a subitization test, a simultaneous process task, it was anticipated that significant correlation would result with each of the three above mentioned tests. A significant correlation was found between the subitization scores and figure copying ($P < 0.05$, $r = 0.29$). However there were no significant correlations found between subitization results and mathematics or reading decoding ($r = 0.06$ and $r = 0.15$ respectively).

Expectation 5. Figure copying did significantly correlate with reading comprehension and mathematics ($r = 0.26$ and $r = 0.27$ respectively), both simultaneous tasks. Although this relation was not as strong as expected, it is acceptable for this age of subject.

Expectation 6. Although digit span has shown significant correlation with reading decoding on previous occasions, it did not relate significantly on these results ($P > 0.10$, $r = 0.14$). In fact its highest relationship with an achievement test was to reading comprehension, a simultaneous process, a finding which was unexpected. No direct explanation can be determined for the apparent reversal of this expectation.

Expectation 7. It was expected that the subjects' abilities to perform the SMM tasks would be highly related to planning strategies therefore highly correlated to the trail-making results. This was found to be true on only three (H-H, V-H, H-A) of the five tests ($r = -0.43$, $r + 0.43$ and $r = -0.25$ respectively). Perhaps this was a result of the following factors. The H-H test was given to all

students first. Students' curiosity and level of anticipation would be highest at this point, therefore more effort was put forth by the subjects. They may also have carefully attempted to test their initial formulated strategies. A second factor may have been related to the sequence V-H itself. Subjects may have been able to better match haptic comparison sequences after having seen a stimulus sequence since a great deal of emphasis is placed on visual activities during this period of educational learning. A final factor affecting the H-A test may have also affected the A-H test (only slightly less significant). The auditory signal was linear in nature as was the haptic signal. This parallelism may have been recognized and used by the subjects as a matching strategy.

Expectation 8. A significant portion of the mathematics program in school deals with algorithmic approach to problem solving. Trail-making has in past studies (Das, Kirby and Jarman, 1978) been used to test individual's planning strategies potential. As expected a significant correlation was found between the results of these two tests ($P < 0.01$, $r = -0.63$).

FACTOR ANALYSIS

To align the statistical analysis of this study with those of previous studies, Jarman (1975) and Das, Kirby and Jarman (1979), the results of individual performances on the twelve tests were submitted to a factor analysis. As summarized in Table 9, four factors are clearly identified.

The first factor is clearly an achievement factor with planning

TABLE 9

PRINCIPAL COMPONENT WITH VARIMAX ROTATION

ON TWELVE VARIABLES

TEST	COMMUNALITIES	1	2	3	4
Reading Decoding	657	647	171	275	366
Reading Comprehension	720	563	088	411	476
Mathematics	754	834	168	097	145
Haptic-haptic Matching	569	711	144	166	-125
Visual-haptic Matching	623	510	602	012	009
Haptic-visual Matching	708	-032	824	141	088
Auditory-haptic Matching	478	180	572	310	-151
Haptic-auditory Matching	654	228	773	-063	009
Figure Copying	534	081	448	534	204
Digit Span	745	089	-022	-078	855
Trail-Making	667	-803	-083	095	080
Subitization	767	101	038	862	110
Component Variance	7.876	2.951	2.261	1.445	1.218
% Component Variance	100	37.47	28.71	18.35	15.47
% Total Variance	65.65	25.60	18.85	12.04	10.16
Eigenvalues		4.216	1.617	1.087	0.958

Decimals omitted

required. The tests which loaded on this factor are reading decoding, reading comprehension, mathematics achievement, haptic-haptic matching, visual-haptic matching and trail-making. Trail-making loading is negative because the test has inverse scoring. Due to the nature of the trail-making tests, it has consistently weighted to the cognitive process of planning (Das, 1981). The intra-modal haptic-haptic matching is a task which involves the repeated use of only one sensing technique and as shown here is performed by the subjects using a planning strategy. The only cross-modal task performed in this manner is the visual-haptic which also weights heavily on factor two. This relationship between the H-H and V-H tasks was also found to be present when tested by correlations as discussed earlier. The tasks performed in trail-making were designed in a manner that would directly enable a subject who was able to identify a performance pattern in the first half of each task to use that pattern to a time advantage in the second half of each task. It is apparent that this ability aided the subjects' performance on the H-H tasks and to a lesser degree on the V-H tests. It might further be argued that this ability is basic to early mathematics skills and word decoding due to the heavy emphasis at the grade one level on the memorization of basic facts and word recognition. These assumptions give support to the importance of teaching problem solving skills when working with a variety of patterned sequences and to a lesser role, in subjects' ability at word comprehension.

Factor II of the matrix is apparently a cross-modal factor with minor support from figure copying. These four tests (V-H, H-V, A-H, H-A) have low to moderate (one exception being V-H to factor one)

loadings on the other factors, indicating that they are performed by a common strategy. The distinctiveness of this factor relative to the other factors will form the basis for some later discussion and speculation.

The third factor is clearly the simultaneous factor. Both figure copying and subitization have relative high loadings on this factor in addition with low or negative loadings for digit span. Reading comprehension has an expected weak loading to this factor as found by Kirby and Das (1977).

Factor IV of the matrix is apparently successive synthesis. Digit span loads extremely high to this factor and low or negative to each of the other factors. Also, the successive processing functions of reading decoding is present.

The results of the factor analyses of the five modality matching tests demonstrate and support previous findings within this study (Table 10). The H-H test continues to stand by itself, as a factor, with lesser support from V-H, while the four intra-modal tests share a common loading. It appears evident that the coding strategies used by the subjects did vary when performing the intra- and cross-modal tasks. This apparent change in the use of strategies at the grade one level will be discussed later as it relates to the teaching of early mathematics education.

In summary of the factor analyses of the 12 variables, the factor solution found by Das (1973 a) and Jarman (1975) was replicated generally in this study. The variations found are notable in connection with the SMM tests and the factors related to these variations for the basis for further analysis of the SMM tests themselves.

TABLE 10

PRINCIPAL COMPONENT WITH VARIMAX ROTATION

WITH SMM TESTS

TEST	COMMUNALITIES	1	2
H-H	908	066	951
V-H	648	598	539
H-V	576	729	209
A-H	572	756	-027
H-A	610	758	190
Component Variance	3.314	2.04	1.28
% Component Variance	100	61.52	38.48
% Total Variance	66.30	40.79	25.51
Eigenvalues		2.422	0.893

CHAPTER V

RESULTS - PART 2

The second major purpose of this study was to carefully study the haptic sensing strategies of a subset of the subjects. The following discussion will review in detail the selection guidelines for Sample 2, an in-depth analysis of cross-modal matching strategies and a comparison between the performance of Sample 2 and the total sample less Sample 2 on the SMM tasks.

Selection of Sample 2

As indicated earlier all subjects were first fiven the H-H test. During this test special attention was given to the specific sensing strategy used by each individual. In particular, subjects were studied as to their deviation from the most frequent strategy, that of a left to right technique using two fingers (fingers 2 and 3 when finger 1 is the thumb) (Sawada, 1979). Since the subjects were drawn from three schools, it was decided to choose eight within each school. Of the 24 subjects thus selected, 22 had complete data sets.

In the large sample (Sample 1), when given the H-H test, 61% of the subjects used the haptic strategy of a left to right (L-R) movement using fingers 2 and 3; 20% had a left to right movement using other finger combinations; 6% used a right to left (R-L) pattern with varied finger combinations; and 13% failed to show any consistent

pattern. Those who used the right-to-left technique were first selected in choosing the subjects for Sample 2. Because of the previous decision to choose 8 subjects per school to allow efficient testing and video-tape recording, 16 subjects were selected who used a L-R movement with various finger combinations and two were chosen from the L-R movement using fingers 2 and 3. The two students who were later deleted from the study used the L-R movement with various finger combinations.

The 12 subjects (13%) who failed to show any consistent pattern were not selected. It was assumed that this behavior was largely due to slower development (as discussed earlier) and the resulting data would probably be non-beneficial to the study.

Methods of Data Collection

The haptic sensing strategies were observed during two specific time periods. The first set of observations was recorded during the H-H testing session (direct observations) and the second set was viewed from VTR taken during the other two testing sessions (VTR observations).

DIRECT OBSERVATIONS

Observations were made on the haptic sensing behaviors of all subjects (Sample 1) during the H-H SMM test. The intent of the observations was to provide a basis for the selection of a smaller sample (Sample 2) and to identify general characteristics of the

haptic sensing strategies used by Sample 2 subjects.

Since only a brief description of the haptic sensing strategies used by Sample 1 was included earlier, a more detailed description is included here. Sawada (1979) found that 73% of 160 grade three students used the L-R pattern when performing intra-modal and cross-modal matching tasks. He claims that "this is not surprising since we read left to right, and the auditory pattern (H-A, A-H) was given left to right". He did not identify the fingers used by the subjects but he did suggest that the use of fingers 2 and 3 (F2, F3, see Appendix F) was the most common. If the subjects in this study who felt L-R, not accounting for fingers used, were added together, it would account for 81% of the total subjects tested (Sample 1).

Sawada also found that 20% of the subjects used a right to left feeling of the beads. This compares to 6% in the present study. Two reasons may account for this difference. First, it was found that 13% of the subjects in the present study were not able to formulate a consistent sensing strategy or fully grasp the nature of the task and second, nearly all work at the grade one level including mathematics is L-R while the computational algorithms of addition and subtraction are becoming well developed at the grade three level and they are most often taught with a R-L sequence.

The other strategies which deviated from the above two techniques in Sawada's study included simultaneous feeling of the beads, rapid back and forth movement without feeling individual beads, starting feeling in the middle of a pattern and missing beads consistently. The first and second strategies were identified in the present study under the direction first moved. In all cases it was L-R. The last

two strategies are highly illustrative of those subjects who showed no behavior pattern.

After the initial observations were noted as discussed above, more specific observations were recorded for the subjects of Sample 2. Attention was paid to six categories of sensing strategies. The distribution for each of these categories as observed is found in Table 11.

1. a. Was the initial movement a L-R sequence?
   b. Was the initial movement a R-L sequence?
2. a. Did the subject use F1?
   b. Did the subject use F2?
   c. Did the subject use F3?
   d. Did the subject use F4?
   e. Did the subject use F5?
3. a. Were the beads felt only once?
   b. Were the beads felt in a back and forth movement?
4. a. Were the beads felt in a deliberate manner?
   b. Were the beads felt in a sliding manner?
   c. Were the beads felt in a spanning manner?
   d. Were the beads felt in an erratic manner?
5. a. Did the subject give indication of subitization?
   b. Did the subject give indication of rehearsal?
   c. Did the subject give indication of another method?
   d. Did the subject give no indication of a method?
6. a. Was a "different" answer scored at point of errot?
   b. Was the complete "different" stimulus felt before answer was scored?

The first movement across the beads was considered as the identifying trait which characterized a L-R or R-L movement. This was also true where subjects tried to simultaneously feel all the beads by spanning the entire sequence. In what direction was movement first taken?

The fingers used often determined a specific sensing strategy. If F1 and F2 were used, the beads were individually squeezed as in a pinching manner (referred to as subgroup x in Table 12). If one finger was used (F2 or F3), a slow sliding across the beads was used (referred to as subgroup y in Table 12). With the use of F2 and F3 or other combinations of fingers, the sensing strategies were of three types: (a) deliberate movement from one bead to the next as in shuffling across, (b) a spanning of the total sequence, like a fanning of the fingers and (c) a rapid back and forth movement (referred to as subgroup z in Table 12).

Although many students felt the bead sequence only once (15 of 22), several students either felt the beads over again as in checking the sequence or rapidly slid the fingers back and forth across the beads until told to lift.

A further strategy qualified the finger movements as deliberate, a definite action; sliding, a smooth continuous action; spanning, a simultaneous feeling action; and erratic, a rapid non-consistent action.

Observed strategies used by the subjects to aid in remembering sequences were noted. Lip movements, talking out loud (which was discouraged) and tapping of finger or pencil (also discouraged) often

provided an indication of specific short-term memory strategies being used. These strategies were discouraged because of the disruptive influence they had on other students being tested at the same time.

Another strategy which deviated from the "normal" was the possibility to record a "different" answer without feeling the total comparison sequence. Since a variation in the comparison stimuli often occurred at the beginning or in the middle of a pattern, an answer of "different" could easily be determined at the point where it occurred in the comparison sequence.

The above observations were noted during the H-H testing sessions for the Sample 2 subjects. It should be noted that if the subject was not performing a specific behavior, its absence was not directly recorded. A summary of the direct observations is found in Table 11.

FINDINGS RELATED TO DIRECT OBSERVATIONS

The findings as they relate to the direct observations will be discussed as they relate to mathematics ability, individual SMM tests (H-H, V-H, H-V, A-H and H-A) and the total SMM scores. Mathematics scores have been chosen over either reading score (decoding or comprehension) for two reasons. First, the assumed connection between mathematics and the SMM tasks. As suggested by Jarman (1975) and Sawada (in press), subjects used counting as an aid in matching the SMM tasks. It was also felt that chunking (subitization) and rehearsing, both skills used in the learning of mathematics, would play an important role. Second, the assumed relationship between mathematics scores and haptic sensing strategies.

TABLE 11

DIRECT OBSERVATIONS OF SAMPLE 2

SUBJECT	OBSERVATIONS AS PER CODE																		
	1		2					3		4				5				6	
	a	b	a	b	c	d	e	a	b	a	b	c	d	a	b	c	d	a	b
A	*			*	*	*		*			*			*	*				*
B	*		*	*				*		*						*			*
C	*				*			*			*						*		*
D	*			*	*	*	*	*				*		*					*
E	*			*	*				*		*						*		*
F	*		*	*				*		*				*					*
G	*		*	*				*		*				*	*			*	
H		*		*					*		*			*					*
I		*		*	*	*		*				*				*			*
J	*			*	*	*		*			*			*	*				*
K	*			*	*				*			*					*	*	
L		*		*				*			*					*			*
M		*	*	*					*	*							*		*
N	*			*	*	*		*					*	*					*
O	*				*				*		*						*		*
P	*			*				*			*			*	*			*	
Q	*			*				*			*			*	*				*
R	*			*	*	*		*				*					*		*
S	*			*	*	*			*				*	*	*				*
T		*			*	*		*			*			*	*				*
U	*			*				*			*			*	*				*
V	*			*					*		*						*		*
TOTAL	17	5	4	20	12	7	1	15	7	4	12	3	3	12	8	3	7	3	19

The means of each subgroup as determined by the direct observations were calculated (See Table 12) to aid in the following discussion. No other statistical analysis was attempted because of the small number of observations in many of the subgroups.

1. Direction of Movement

As discussed earlier, the subjects were divided as to the initial direction of movement (L-R, R-L). It was anticipated that during the A-H and H-A tests, the subjects using the R-L movement (group 1-b) may have difficulty since the auditory stimuli are presented in a left to right direction. This was found to be true. Group 1-b had consistently higher mean scores than did group 1-a on the SMM tests, except for the two SMM tests involving the auditory mode.

It also appears that the five subjects who did feel R-L, had a more definite strategy for matching as their total SMM test mean was higher than the mean of the L-R group.

The difference in the means of the mathematics scores of the two groups was less than one.

2. Finger Selection

The subjects were grouped into three groups according to the fingers used during the haptic sensing: (x) those who used F1 and F2 (4 subjects), (y) those who used only one finger, F2 or F3 (8 subjects), and (z) those who used other groups of fingers (10 subjects). Little overall difference was seen between group x and group y. Group z had

TABLE 12

MEANS FOR SAMPLE 2 SUBGROUPS AS
IDENTIFIED BY DIRECT OBSERVATIONS

OBSERVATION CODE	n	MATH TEST	SMM TESTS H-H	V-H	H-V	A-H	H-A	SMM TOTAL
1. a	17	57.0	15.0	18.9	16.7	16.4	15.6	82.6
b	5	57.6	16.8	22.4	18.2	15.8	14.6	87.8
2. x	4	56.3	14.8	20.5	16.0	14.5	15.0	80.8
y	8	57.1	16.3	18.6	17.1	15.8	13.3	81.0
z	10	57.5	15.0	20.2	17.4	17.3	17.3	87.2
3. a	15	57.0	15.0	20.8	18.1	16.9	16.4	87.3
b	7	57.4	16.3	17.3	14.7	14.7	13.3	76.3
4. a	4	56.3	14.8	20.5	16.0	14.5	15.0	80.0
b	12	57.6	15.7	19.8	17.3	16.7	15.1	84.5
c	3	56.3	16.0	21.3	18.3	16.7	19.7	92.5
d	3	53.7	14.7	16.7	16.0	16.3	13.0	76.7
5. a	12	57.3	14.8	19.3	17.7	16.8	17.2	85.5
b	8	57.3	14.9	20.3	19.1	17.0	18.4	89.6
c	3	56.0	15.3	22.7	16.7	16.7	12.7	84.0
d	7	57.4	16.4	19.1	16.1	15.0	13.6	80.3
6. a	3	57.4	15.5	19.4	16.7	16.2	15.3	83.2
b	19	55.7	14.7	21.7	19.0	16.3	16.0	87.7
TOTAL	MEAN	57.1	15.4	19.7	17.1	16.2	15.4	83.8

a strong performance on the two cross-modal tests involving the auditory mode, and showed a high SMM total mean. Although there is little difference between the mathematics means, group z was higher.

Seven of the 10 students in group z used three or more fingers and three of these seven attempted to span the total sequence, simultaneous feeling. Perhaps when students were able to get a complete impression of the stimulus, they were able to perform better. This is supported by the SMM total mean for group 4-c ($\overline{X}$ = 92.5)

3. Repeated Feelings

The subjects (group 3-a) who felt the beads only once did better on the SMM tests than did the subjects (group 3-b) who repeatedly kept feeling the beads. It was expected that group 3-a would use a short-term memory strategy in performing the SMM matching tasks. There was little difference (inverse factor) found between these groups in mathematics ability.

4. Manner of Feeling

Of the four types of feeling strategies identified, the subjects who simultaneously felt the beads (group 4-c) had equal or higher scores on the individual SMM tests. They also had the highest SMM total mean score. Those who felt in a sliding manner (group 4-b) had the second highest SMM total mean score, while those who felt in an erratic manner (group 4-d) were lowest.

Although little difference was found in the mathematics mean scores between the four groups, one observation is noted. Group 4-d,

erratic movement, seemed to have no systematic strategy of sensing the patterns. They also had the lowest mathematics mean score. The lack of strategy development may reflect lower mathematics achievement. What significance is this finding to mathematics teaching?

5. Matching Strategies

The two matching strategies of clustering the dots into small groups, often referred to as subitization and the technique of counting individual beads with pauses, as found by Jarman (1975) and Sawada (1979), were both classified as subitization in this study. Of the various strategies identified, rehearsing (group 5-b) was the most effective, followed by subitization (group 5-a). The three subjects (group 5-c) who gave indication of a method different from those above, had the third highest mean, while those with no (group 5-d) indicated method of matching had the lowest mean score.

Mathematics ability as indicated in the mean scores varied little among the four groups.

6. Scoring "Different" Answers

The three subjects (group 6-a) who scored the "different" answer before they had felt the complete comparison stimulus did not score higher than those who felt the complete comparison stimulus (group 6-b). It had been expected that those who were able to recognize a "different" task early would perform better. The inability of subjects to do this may then be due to some other factor and not to understanding alone.

Unlike the other observations, mathematics mean scores were

higher for group 6-1 than for group 6-b.

VTR OBSERVATIONS

During each of the last two testing sessions for each of the Sample 2 subjects, a video-tape recorder was positioned so as to record their haptic sensing maneuvers. The recordings were later reviewed and observations noted.

Specific observations were recorded in six areas of concentration.

1. Did the subject continue to use the same direction of movement?
2. Was the finger selection varied and if so to which fingers?
3. Was the manner of feeling consistent throughout the SMM tests and if not when did it vary?
4. Did the subject hesitate when feeling the longer sequences?
5. Did the haptic sensing behavior show loss of concentration during the SMM tests?
6. Did the subject deliberately establish the starting end point before feeling the stimulus?

Assuming that consistent sensing strategies would give opportunity for better performance by the subjects, consistency was checked in three areas: L-R vs R-L movement, varied finger selection and manner of feeling. It was expected that if subjects varied their method of haptic sensing, it was because they were searching for a better matching strategy as they were adjusting to a different mode of stimulus.

Hesitating when feeling the longer clusters (3 or 4 beads) in the

sequences was also noted. Were students counting as they hesitated or were they using some other strategy?

As suggested earlier, grade one students seemed to be the lower limit for students able to perform the SMM matching tasks. To further verify this, students were checked as to the level of concentration during the testing sessions.

Although all students established the starting point, some students seemed to be over anxious in getting the right starting point. This behavior was also noted.

The above observations were noted during the final two SMM testing sessions for the Sample 2 subjects. It should again be noted that if the behavior was not being practiced, it was not directly recorded. A summary of the VTR observations as they relate to the six questions identified earlier is found in Table 13. A "+" on the table denotes a "yes" answer and a "-" denotes a "no" answer. All alterations in finger use were to add more fingers and these are indicated. The SMM tests during which subjects changed the manner of feeling are also shown.

TABLE 13

VTR OBSERVATIONS OF SAMPLE 2

SUBJECT	OBSERVATIONS AS PER CODE					
	1	2	3	4	5	6
A	+	+ F4	- A-H, H-A	+	+	-
B	+	-	+	-	+	-
C	+	-	+	-	-	-
D	-	-	- V-H	+	-	+
E	+	-	+	-	-	+
F	+	-	+	-	+	-
G	+	-	+	-	-	-
H	+	+ F3	+	+	-	+
I	-	-	- A-H, H-A	+	+	-
J	+	-	+	+	-	+
K	+	-	+	-	-	-
L	+	-	- H-V	+	-	-
M	-	+ F3	+	+	-	+
N	-	-	+	+	+	-
O	+	-	+	+	-	-
P	-	+ F3	- H-A	-	-	-
Q	+	+ F3	+	+	+	+
R	+	-	+	+	-	-
S	+	-	- V-H, H-V	+	+	-
T	-	-	- A-H, H-A	+	+	-
U	+	+ F3	- A-H	-	-	-
V	+	+ F3, F4	+	+	-	-
TOTAL: YES	16	7	14	14	8	6
NO	6	15	8	8	14	16

FINDINGS RELATED TO VTR OBSERVATIONS

The findings as they relate to the VTR observations will be discussed in two sections: deviant behaviors and mean comparisons.

Deviant Strategies

Question 1. Six of the 22 subjects changed their direction of movement during the testing sessions: four who started with a L-R movement went to a R-L movement and two who started with a R-L went to a L-R movement. Of the four who changed to R-L movement; one was during the V-H test only, one showed no preference for L-R or R-L and varied regularly, and two used a R-L movement as if checking the sequence. One subject, who went from R-L to L-R made the change on the first cross-modal test and the other subject changed during the A-H test after he had taken the H-A test.

Question 2. Finger 3 was added in 5 of 7 changes in finger selection, finger 4 was added once and fingers 3 and 4 were added once. In no instance did subjects not use the fingers which they selected to use on the first (H-H) SMM test.

Question 3. In summarizing the changes in sensing movement, no consistent pattern can be identified. Of the 8 subjects who switched, 3 went to a rapid back and forth movement, 2 reversed the direction of haptic sensing, 2 seemed to settle on a more systematic system during their last SMM test and one changed to feeling the beads only once during the V-H and H-V tests. The first change appears to be related to individual frustration, while the last three changes are

probably related to individuals developing a more satisfactory haptic sensing strategy.

Question 4. As discussed earlier, 12 subjects gave indication of subitization. Nine of these subjects also hesitated when sensing longer clusters (3 or 4 beads). Five additional subjects hesitated on the long clusters but did not give evidence of subitization. Only three subitizing subjects did not hesitate.

Question 5. Eight of the 22 subjects showed signs of loss of concentration during the testing sessions. Most often their hand movement stopped and no haptic sensing was taking place. In all cases this happened after question 25 and when taking the A-H or H-A tests. This further illustrates the developmental limit of the grade one subjects.

Question 6. On the last observation, 6 subjects used deliberate actions in establishing the starting point of each sequence. It appeared as if they did not trust their first feeling of the end block and needed to firmly establish where the sequence began. It is also possible that the reaction is just a nervous response to the testing program.

Mean Comparisons As Identified By Study Questions

The means were again calculated for the subgroups of subjects as determined by the observations (See Table 14).

Question 1. Those subjects who changed direction during the testing sessions did better on the V-H and H-V cross-

TABLE 14

MEANS FOR SAMPLE 2 SUBGROUPS AS IDENTIFIED

BY VTR OBSERVATIONS

OBSERVATION CODE	n	MATH	SMM TESTS H-H	V-H	H-V	A-H	H-A	SMM TOTAL
1+	16	56.5	15.2	19.1	16.8	16.3	15.1	82.3
1-	6	57.4	16.2	21.2	17.8	16.2	15.1	86.5
2+	7	57.4	16.6	19.1	17.7	15.9	15.1	84.4
2-	15	57.0	14.9	19.9	16.7	16.4	15.5	83.5
3+	14	57.2	15.9	19.6	16.4	15.5	14.7	82.0
3-	8	57.0	14.8	19.9	18.1	17.5	16.6	86.9
4+	14	57.6	16.6	20.1	17.9	15.9	16.4	86.9
4-	8	56.2	13.4	19.0	15.5	16.8	13.8	78.4
5+	8	56.4	14.6	19.1	17.5	16.9	15.9	84.0
5-	14	57.8	15.9	20.0	16.8	15.9	15.1	83.6
6+	6	59.0	16.8	21.0	16.8	15.8	17.8	88.7
6-	16	56.4	14.9	19.1	17.2	16.4	14.5	81.9
TOTAL		57.1	15.4	19.7	17.1	16.2	15.4	83.8

modal tests and no difference was found in their performance on the A-H and H-A cross-modal tests. It seems apparent that subjects who changed strategies did so beneficially. This strategy adjustment to better performance is also reflected in a higher mathematics achievement mean score.

Question 2. Variance in the selection of fingers used during the haptic sensing had little overall difference on the SMM tests as in indicated SMM total mean scores. Little difference was found in their mathematics achievement as well.

Question 3. After the initial H-H test, the subjects who adjusted the manner of haptic sensing performed better on each of the four remaining SMM tests. These changes also showed the ability of grade one students to self-adjust processing techniques and sensing strategies to an advantage.

Question 4. As previously discussed, subitization was a dominant process used by subjects on the SMM tasks. The haptic sensing strategy of hesitation when sensing the longer clusters does support this finding. Subjects were counting the clustered beads when performing the individual tasks. A small difference in mathematics ability also supports this finding.

Question 5. The developmental level of the subjects again gains support as it was observed that the loss of concentration near the end of the tests did not affect the subjects' performance. It is probable that the subjects, who did give indication of this factor, were also only guessing by the time they reached the more difficult questions.

Question 6. The six subjects who took the extra time to firmly establish the starting point, performed much better than those who didn't. This strategy, which may reflect the intent of the subjects to have a good beginning, as used by the subjects enables them to perform better on both the SMM tests (SMM total score) and on the mathematics achievement test.

INTERRELATIONS BETWEEN SAMPLES

Independent samples were determined for the purpose of comparing the performance of Sample 2 with the performance of the other samples. Tow new samples were also identified. Sample 1A consisted of those subjects who were part of Sample 1 but not part of Sample 2 (Sample 1 minus Sample 2, n = 68). Sample 1B (n = 56) consisted of those subjects who were part of Sample 1A but not the subjects who were unable to consistently perform the SMM tasks. A summary of the means of the mathematics and SMM tests for each of these samples is presented in Table 15.

One observation is noteworthy. The subjects who had defined haptic sensing strategies (Sample 2) performed better in all instances than did the other samples. This seems to suggest that the L-R movement, using F2 and F3 is somewhat inherent to the haptic sensing SMM tasks of this type and subjects who differ from this behavior do so because of developed strategies which aid in higher performance levels.

Because of the consistently higher performance by Sample 2 (Table 15) on the SMM tests it was then decided to compare the

TABLE 15

MATHEMATICS AND SMM TEST MEANS FOR

SAMPLES 1, 1A, 1B AND 2

TEST	SAMPLE 1 n = 90	SAMPLE 1A n = 68	SAMPLE 1B n = 56	SAMPLE 2 n = 22
Mathematics	56.2	55.9	56.9	57.1
H-H	13.8	13.3	13.8	15.4
V-H	16.5	15.5	16.1	19.7
H-V	15.6	15.1	15.3	17.1
A-H	14.6	13.9	14.2	16.2
H-A	14.3	14.0	14.5	15.4

cognitive process tests' means. The summary of these means is found in Table 16. A parallel finding is also present here. Sample 2 subjects consistently manifest higher level cognitive processes in planning, successive processing and simultaneous processing.

TABLE 16

COGNITIVE PROCESS TESTS MEANS FOR

SAMPLES 1, 1A, 1B AND 2

TEST	SAMPLE 1 n = 90	SAMPLE 1A n = 68	SAMPLE 1B n = 56	SAMPLE 2 n = 22
Trail-making	220.4	227.2	217.1	199.3
Figure copying	7.2	6.9	7.1	8.3
Digit span	4.6	4.6	4.6	4.7
Subitization	11.6	11.4	11.5	12.1

CHAPTER VI

CONCLUSIONS, IMPLICATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The purposes of this research were centered around two central issues: (1) to compare the performance of grade one students on selected modality matching tasks and cognitive process tasks with the results of similar tasks performed by older students (grades three and four), and (2) to study the varied haptic sensing strategies of grade one students and to determine if they were related to mathematics ability.

Conclusions with Respect to Performance

Subjects at the grade one level appear to be the youngest for whom the SMM type task is appropriate. Support for this conclusion is found repeatedly during several testing situations.

1. The significantly better performance of the older one-third of the sample, when compared with that of the other thirds.
2. The inability of several students to satisfactorily perform the SMM tasks.
3. The inability of many subjects to maintain concentration to the end of the SMM tests.

In general, the established relationships between cognitive processes and scholastic abilities were supported (Das, Kirby and Jarman, 1978). Simultaneous processing was supported by a

relationship between figure copying and reading comprehension. Planning skills were supported by relationships among trail-making, mathematics achievement and the SMM tests. Successive processing was supported by its expected correlation to digit span but not to reading decoding.

The strategy of planning is most used by grade one students in relation to achievement in reading and mathematics. Planning weighted highest with scholastic achievement in the factor analysis test while simultaneous and successive processing were very low.

Grade one students employed various skills when performing intra-modal matching tasks and cross-modal matching tasks. Evidence strongly supports that the factors used when performing cross-modal skills continued to be used for the various cross-modal tests (V-H, H-V, A-H and H-A). A different set of factors, however, was dominantly used by the subjects during the intra-modal tests (H-H) as evidenced in the analysis.

Conclusions with Respect to Haptic Sensing Strategies

Counting strategies and subitization strategies aid the subjects in performing the SMM tasks. Subjects who used consistent and observable strategies performed better not only on the modality tests but also on all of the cognitive process tests.

As supported by previous findings (Jarman, 1975; Sawada 1979 c), intelligience, as indicated by higher scholastic achievement, is directly related to the ability of grade one students to perform SMM tasks.

The development level of most grade one subjects is such that the ability to adjust or change haptic sensing strategies is present and it can be used to improve performance. Students who altered their direction of movement (L-R, R-L) and the manner of feeling the beads (deliberate, sliding, spanning and erratic) did perform better than students who did not make these adjustments.

Students who deviated from the normal learning procedures may not be the "under-achievers" but the "over-achievers". This is supported by the high performance of the subjects who used R-L haptic sensing strategy throughout the SMM tests. They achieved higher scores on three (H-H, V-H, H-V) SMM tests and a lower score on only one SMM test (A-H).

DISCUSSION AND INTERPRETATION

The statistical analyses that have been conducted in this study have been essentially of two types. First, correlational and factor analytic techniques have been used to identify cognitive strategies among the subjects. Second, various analysis techniques which assess mean levels of performance for the groups as defined by haptic sensing strategies have been compared. The information given from these two perspectives support several instructional theories used by teachers during the early years of students' formal education. However, one seems to dominate and will be discussed here.

Developmental psychologists suggest that children pass through stages of growth, at which time specific characteristics of cognitive functioning appear or disappear. As students enter their formal

education years, one of the characteristics which appears is known as accomodation: the process of selection which assigns a learning strategy to a learning situation to obtain the most benefit for one's self.

In the present study, this characteristic was found to be present in many of the students as they altered their haptic and cognitive strategies to better their individual performances. A brief summary of support findings is now included.

1. Significant correlations were found between the scores of three of the five SMM tests and the trail-making scores. The planning strategies as determined by the trail-making test were used by subjects when tested on the SMM tests (expectation 7, page 46).

2. Significant correlation was found between trail-making and mathematics scores. The subjects who used planning skills in performing early mathematics concepts also had a higher mean score on the planning strategy test (expectation 8, page 47).

3. The first and dominant factor as determined by factor analysis, was earlier identified to be a planning factor. Students having planning skills did have a performance advantage over those students not having planning skills (factor one, page 47).

4. The second factor, a cross-modal factor, indicates a single strategy was used by the subjects in performing cross-modal tasks. The ability of students to select a varying strategy when confronted with a different type of stimulus is seen as an additional application of planning skills present in beginning students (factor two, page 49).

5. The subjects who used a R-L movement as a sensing strategy did have a higher SMM mean score. Although this strategy was not

found to be common, it was used in a definite manner having positive results (direction of movement, page 59).

6. The subjects who had an erratic sensing strategy, scored lowest in both the SMM tests and the mathematics test. Their inability to formulate a consistent sensing strategy directly affected their performance resulting in low means, often little better than chance (group 4-b, page 61).

7. The subjects who used the sensing strategies of rehearsing and subitization did significantly better on both the mathematics and the SMM tests (group 5-b, page 62).

8. The students who altered the direction of sensing during the SMM tests had a higher SMM mean score than students who did not. It was also found that these students had higher performance levels in mathematics achievement than did the students who used the same strategy throughout the SMM testing (question 1, page 66).

9. The students in Sample 2 (selected because of having a defined strategy) did better on all tests; scholastic, sensory matching and cognitive, than did the other students who were tested.

These findings give support to instructional theories which suggest that students need to be challenged with new situations, with new stimuli, with innovative problem solving, with creative devices. The elementary mathematics teacher can play a major role in the development of the functioning and strengthening of planning skills and strategy accommodation in young students.

Traditionally, however, lower elementary mathematics is often taught with emphasis on the memorization and application of basic facts. Educational philosophy has been altered due to public

utterances of "Back to the Basics" and "Accountability for Teachers" leaving little chance for the use of discovery and strategy development. The findings in this study suggest that students need to be allowed to self-test their planning skills and sensing strategies in finding solutions to the problems they face. They need to learn to attach a new situation or problem and if refuted, to reattack with a varying strategy. Students must be allowed to develop and use personal planning skills. This study found that students who were able to do this, did perform consistently better not only in mathematics achievement but also in various cognitive processes and on the SMM tasks.

Mathematics, as a discipline, allows that freedom, that flexibility. Teachers of mathematics must give serious attention to the development of activities which will allow young children to develop, select and use planning skills and strategies.

IMPLICATIONS FOR PROBLEM SOLVING IN ELEMENTARY SCHOOL MATHEMATICS

The results and conclusions of this study provide direct support to the recent position taken by the National Council of Teachers of Mathematics. In a position paper, the Council states that "problem solving be the focus of school mathematics in the 1980's". In defining this recommendation they further state that "the mathematics curriculum should be organized around problem solving" and that "mathematics teachers should create classroom environments in which problem solving can flourish".

In this study grade one students were confronted with SMM tasks

which were new and challenging to them. The tasks were in fact problem solving situations for the students. They were required to function in a novel environment. Because they had no direct training in performing SMM tasks prior to the testing sessions they had to rely on their personal creativity in selection and utilization of successful skills and strategies. What was the result?

Many of the students performed very successfully. These students did select and plan varied strategies in performing the tasks. They did alter their originally selected strategies to increase performance levels. Many students used different strategies to perform the identical tasks. What importance is this for the mathematics educator in light of the above recommendation?

Assuming that problem solving is primarily a creative activity, students should be presented with problem solving situations which do not exclusively depend on routines and formulas. This suggests that the mathematics teacher provide opportunities for students to develop and test a wide variety of means and strategies. Problem solving needs to be taught with a de-emphasis on traditional formats and routines. Students must be allowed to transfer the skills and strategies of problem solving from known situations to unknown situations.

It was also found that students changed and varied their strategies during the SMM task to their advantage. Teachers need to devise problems which demand of the students a greater flexibility in strategy and skill development and application. "Textbook problems" do not permit students to experience the full range of strategies and abilities actually demanded in real-life problems.

It was also found that the students who were unable to select and plan varied strategies when asked to perform the SMM tasks were either unable to do so or did so with a performance level equal to or below chance (50%). It is possible that these students would have also been successful had they had more and varied experiences in problem solving activities. Teachers of mathematics cannot assume that such development will take place without specifically planned curricular activities.

The primary implication as supported by the results of this study is to give a confirmed yes to the NCTM number one recommendation. Lower elementary students (grades 1-3) can conceptualize the issues as found in mathematical problems, they can discover patterns and similarities between problems, and they can select and choose skills and strategies in finding solutions to the problems. The teacher of mathematics must then allow for the use and development of these abilities. Experiences must be created which will promote an attitude of curiosity and exploration, a challenge to develop skills and strategies and the satisfaction of success for the elementary mathematics student.

SUGGESTIONS FOR FURTHER RESEARCH

There are many directions that research related to modality matching could take. Four are suggested here.

The first recommendation is related to the varied strategies used by subjects on intra-modal matching tasks and cross-modal matching tasks as indicated by the results of factor analysis. These

matching strategies need to better clarified in relation to simultaneous and successive synthesis and planning techniques. Research in this direction could well incorporate socio-cultural factors as well.

A second direction in which research is needed is the replication of the SMM testing on a wider sampling of grade one subjects with the inclusion of other modality matching tests. Sawada (1979, in preparation) did incorporate nine such tests in his study, including visual-visual matching (V-V), visual-auditory matching (V-A), auditory-visual matching (A-V), and auditory-auditory matching (A-A) in addition to the five used in this study. In doing this extended research, careful attention should be given to the matching strategies used.

The third direction for future study is the use of achievement tests in connection to the present study. True achievement tests, with high discriminating power, need to be developed. Not only would this allow better comparative judgments but would provide the research with more direct information of the cognitive processes used by developing students.

A fourth recommendation is related to the potential abilities of lower elementary students to perform varied problem solving activities and the effect that training would have on individual performances. This research might be designed to use the traditional control-noncontrol environment. When selecting problem activities, the researcher should emphasize novel nontextbook type problems. Attention should also be given to problems having varied

means of finding a solution. Research in this direction could shape future elementary mathematics curriculum design.

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APPENDIX A

SMM Tests

HAPTIC-HAPTIC MATCHING

Hello. Today we are going to feel some patterns of beads. We are going to play a game with these beads. We will see if some of them are the <u>same</u> as others, and see if some of them are different from others.

Put your hand through the cuff, please, and see if you can feel the beads?

(Stimulus part of Example 2 is felt.) 10 seconds

Lift your hand from the beads so we may give you some new beads to feel. Feel the beads.

(Comparison part of Example 2 is felt.) 7 seconds

Lift your hand. Did you notice that the last beads were not the same as the first beads? Let's feel both of them again. Ready, feel the first beads.

(Stimulus part of Example 2 is felt.) 5 seconds

Lift your hand... now feel the first beads. And now the second beads.

(Comparison part of Example 2 is felt.) 5 seconds

Lift your hand. The first beads were not the same as the second beads, were they? They were different from each other. Let's feel some beads that are the same as each other.

Ready? Feel.

(Stimulus part of Example 1 is felt.) 5 seconds

Lift your hand...feel.

(Comparison part of Example 1 is felt.) 5 seconds

Lift your hand. Those were the same as each other, weren't they? How can we write on paper that they were the same as each other? On

the paper in front of you, the words same and different are written down for each group of beads that you will feel. Let's feel some more beads and see how we would write the answer. Ready? Feel.

(Stimulus part of Example 1 is felt.) 4 seconds

Lift your hand...feel.

(Comparison part of Example 1 is felt.) 4 seconds

Lift your hand. They were the same, weren't they? If we look at number 1 on the page, a circle is drawn around the word same to show that they were the same.

Let's feel the beads for number 2.

Ready? Feel.

(Stimulus part of Example 2 is felt.) 4 seconds

Lift your hand...feel.

(Comparison part of Example 2 is felt.) 4 seconds

Lift your hand. Those were different, weren't they? If we look at number 2 on the page, a circle is drawn around the word different to show that they were different.

Let's feel the beads for number 3.

Ready? Feel.

(Stimulus part of Example 3 is felt.) 4 seconds

Lift your hand...feel.

(Comparison part of Example 3 is felt.) 4 seconds

Lift your hand. Those beads were different so a circle has been drawn around the word different for number 3. Now, would you like to try some? Use the pencil that you have in front of you to circle the right answer.

Let's do number 4.

Ready? Feel.

(Stimulus part of Example 4 is felt.) 4 seconds

Lift...feel.

(Comparison part of Example 4 is felt.) 4 seconds

Lift.

(Pause for 15 seconds.)

Did you circle the word same for number 4? That is the right answer.

Let's try another one. We will do number 5.

Feel.

(Stimulus part of Example 5 is felt.) 4 seconds

Lift...feel.

(Comparison part of Example 5 is felt.) 4 seconds

Lift.

(Pause for 15 seconds.)

Did you circle the word different for number 5? That is the right answer.

Let's do some more of these. After each group of beads that you feel, circle the right answer on your paper, to show if they were the same or if they were different.

Number 6.

Feel.

Lift...feel.

Lift.

HAPTIC-VISUAL MATCHING

Hello. Today we are going to feel some patterns of beads. We are

also going to look at some pictures. All of the pictures will have dots in them. We are going to play a game with these beads and pictures. We will see if some of the beads are the <u>same</u> as some of the pictures. We will also see if some of the beads are <u>different</u> from some of the pictures.

Put your hand through the cuff, please, and see if you can feel the beads.

(Stimulus part of Example 2 is felt.) 10 seconds

Please lift your hand off the beads. Now let's look at the dots in this picture.

(Comparison part of Example 2 is seen.) 5 seconds

Did you notice that the beads were not the same as the dots in the picture? Let's compare them again. Ready, feel the beads?

(Stimulus part of Example 2 is felt.) 4 seconds

Lift your hand, and now look at the dots.

(Comparison part of Example 2 is seen.) 5 seconds

The beads were not the same as the dots in the picture, were they? They were different from each other. Let's compare some beads and dots that are the same as each other.

Ready? Feel.

(Stimulus part of Example 1 is felt.) 5 seconds

Lift your hand...look at the dots.

(Comparison part of Example 1 is seen.) 5 seconds

Those were the same as each other, weren't they? How can we write on paper that they were the same as each other? On the paper in front of you, the words same and different are written down for each set of beads and dots that we will compare. Let's compare some more beads

and dots and see how we would write down the answer.

Ready? Feel.

(Stimulus part of Example 1 is felt.) 4 seconds

Lift your hand.

(Comparison part of Example 1 is seen.) 5 seconds

They were the same, weren't they? If we look at number 1 on the page, a circle is drawn around the word same, to show that they were the same.

Let's feel the beads and look at the dots for number 2.

Ready? Feel.

(Stimulus part of Example 2 is felt.) 4 seconds

Lift your hand.

(Comparison part of Example 2 is seen.) 5 seconds

The beads were different from the dots, weren't they? If we look at number 2 on the page, a circle is drawn around the word different to show that they were different.

Let's feel the beads and look at the dots for number 3.

Ready? Feel.

(Stimulus part of Example 3 is felt.) 4 seconds

Lift your hand...look at the dots.

(Comparison part of Example 3 is seen.) 5 seconds

The beads were different from the dots, so a circle has been drawn around the word different for number 3. Now, would you like to try some? Use the pencil that you have in front of you to circle the right word after you have felt the beads and seen the dots.

Let's do number 4 now.

Ready? Feel.

(Stimulus part of Example 4 is felt.) 4 seconds

Lift your hand.

(Comparison part of Example 4 is seen.) 5 seconds

(Pause for 15 seconds.)

Did you circle the word same for number 4? That is the right answer.

Let's try another one. We will do number 5.

Feel.

(Stimulus part of Example 5 is felt.) 4 seconds

Lift.

(Comparison part of Example 5 is seen.) 5 seconds

(Pause for 15 seconds.)

Did you circle the word different for number 5? That is the right answer.

Let's do some more of these. After you feel the beads and see the dots, circle the right answer on your page to show if they were the same or if they were different.

Number 6.

Feel.

Lift.

VISUAL-HAPTIC MATCHING

Hello. Today we are going to look at some pictures. We are also going to feel some patterns of beads. All of the pictures will have dots in them. We are going to play a game with these pictures and beads. We will see if some of the pictures are the <u>same</u> as some of

the beads. We will also see if some of the pictures are <u>different</u> from some of the beads.

Let's look carefully at the dots in this picture.

(Stimulus part of Example 2 is seen.) 5 seconds

Now let's feel some beads. Put your hand through the cuff so you can feel the beads. Do you feel the beads?

(Comparison part of Example 2 is felt.) 10 seconds

Lift your hand from the beads.

Did you notice that the dots you saw were not the same as the beads you felt? Let's compare them again. Ready for the dots?

(Stimulus part of Example 2 is seen.) 5 seconds

Now feel the beads.

(Comparison part of Example 2 is felt.) 5 seconds

Lift your hand from the beads.

The dots in the picture were not the same as the beads, were they? They were different from each other. Let's compare some dots and beads that are the same as each other.

Ready?

(Stimulus part of Example 1 is seen.) 5 seconds

Feel the beads.

(Comparison part of Example 1 is felt.) 5 seconds

Lift your hand.

(Pause)

Those were the same as each other, weren't they? How can we write on paper that they were the same as each other? On the paper in front of you the words same and different are written down for each set of dots and beads that we will compare. Let's compare some

more dots and beads and see how we would write down the answer.

Ready?

(Stimulus part of Example 1 is seen.) 8 seconds

Feel.

(Comparison part of Example 1 is felt.) 5 seconds

Lift your hand. They were the same, weren't they? If we look at number 1 on the page, a circle is drawn around the word same, to show that they were the same.

Let's look at the dots and feel the beads for number 2.

Ready?

(Stimulus part of Example 2 is seen.) 5 seconds

Feel.

(Comparison part of Example 2 is felt.) 5 seconds

Lift your hand. The dots were different from the beads, weren't they? If we look at number 2 on the page, a circle is drawn around the word different to show that they were different.

Let's look at the dots and feel the beads for number 3.

Ready?

(Stimulus part of Example 3 is seen.) 5 seconds

Feel.

(Comparison part of Example 3 is felt.) 5 seconds

Lift your hand. The dots were different from the beads, so a circle has been drawn around the word different for number 3. Now, would you like to try some? Use the pencil you have in front of you to circle the right word after you have seen the dots and felt the beads.

Let's do number 4

Ready?

(Stimulus part of Example 4 is seen.) 5 seconds

Feel.

(Comparison part of Example 4 is felt.) 5 seconds

Lift.

(Pause for 15 seconds.)

Did you circle the word same for number 4? That is the right answer.

Let's try another one. We will do number 5.

Ready?

(Stimulus part of Example 5 is seen.) 5 seconds

Feel.

(Comparison part of Example 5 is felt.) 5 seconds

Lift.

(Pause for 15 seconds.)

Did you circle the word different for number 5? That is the right answer.

Let's do some more of these. After you see the dots and feel the beads, circle the right answer on your page to show if they were the same or if they were different.

Number 6.

Ready?

Feel.

Lift.

AUDITORY-HAPTIC MATCHING

Hello. Today we are going to listen to some patterns of sounds. We are also going to feel some beads. All of the sounds will be little beeps. We are going to play a game with these sounds and beads. We will see if some of the sounds are the same as some of the beads. We will also see if some of the sounds are different from some of the beads.

Let's listen carefully to some beeps.

(Stimulus part of Example 2 is heard.) 4 seconds

Now, let's feel the beads. Put your hand through the cuff. Do you feel the beads?

(Comparison part of Example 2 is felt.) 10 seconds

Lift your hand from the beads.

Did you notice that the beeps were not the same as the beads? Let's compare them again. Ready for the beeps?

(Stimulus part of Example 2 is heard.) 4 seconds

Now, feel the beads.

(Comparison part of Example 2 is felt.) 4 seconds

Lift your hand from the beads.

The beeps were not the same as the beads, were they? They were different from each other. Let's compare some beeps and beads that are the same as each other.

Ready?

(Stimulus part of Example 1 is heard.) 4 seconds

Feel the beads.

(Comparison part of Example 1 is felt.) 5 seconds

Lift your hand. Those were the same as each other, weren't they?

How can we write on paper that they were the same as each other? On the paper in front of you, the words same and different are written down for each set of beeps and beads that we will compare. Let's compare some more beeps and beads and see how we would write down the answer.

Ready?

(Stimulus part of Example 1 is heard.) 4 seconds

Feel.

(Comparison part of Example 1 is felt.) 4 seconds

Lift your hand. They were the same, weren't they? If we look at number 1 on the page, a circle has been drawn around the word same, to show that they were the same.

Let's listen to the beeps and feel the beads for number 2.

Ready?

(Stimulus part of Example 2 is heard.) 5 seconds

Feel.

(Comparison part of Example 2 is felt.) 4 seconds

Lift your hand. The beeps were different from the beads, weren't they? If we look at number 2 on the page, a circle has been drawn around the word different to show that they were different.

Let's listen to the beeps and feel the beads for number 3.

Ready?

(Stimulus part of Example 3 is heard.) 6 seconds

Feel.

(Comparison part of Example 3 is felt.) 4 seconds

Lift your hand. The beeps were different from the beads, so a circle has been drawn around the word different for number 3. Now, would you like to try some? Use the pencil that you have in front of

you to circle the right word after you have heard the beeps and felt the beads.

Let's do number 4 now.

Ready?

(Stimulus part of Example 4 is heard.) 7 seconds

Feel

(Comparison part of Example 4 is felt.) 4 seconds

Lift.

(Pause for 15 seocnds.)

Did you circle the word same for number 4? That is the right answer.

Let's try another one. We will do number 5.

Ready?

(Stimulus part of Example 5 is heard.) 7 seconds

Feel.

(Comparison part of Example 5 is felt.) 4 seconds

Lift.

(Pause for 15 seconds.)

Did you circle the words different for number 5? That is the right answer.

Let's do some more of these. After you hear the beeps and feel the beads, circle the right answer on your page to show if they were the same or if they were different.

Number 6.

Ready?

Feel.

Lift.

HAPTIC-AUDITORY MATCHING

Hello. Today we are going to feel some beads. We are also going to listen to some patterns of sounds. All of the sounds will be little beeps. We are going to play a game with these beads and sounds. We will see if some of the beads are the <u>same</u> as some of the sounds. We will also see if some of the beads are <u>different</u> from some of the sounds.

Put your hand through the cuff, please, and see if you can feel the beads.

(Stimulus part of Example 2 is felt.) 10 seconds

Please lift your hand from the beads.

Now let's listen carefully to some beeps.

(Comparison part of Example 2 is heard.) 4 seconds

Did you notice that the beads were not the same as the beeps? Let's compare them again.

Ready?

Feel the beads.

(Stimulus part of Example 2 is felt.) 4 seconds

Lift your hand from the beads and listen to the beeps.

(Comparison part of Example 2 is heard.) 4 seconds

The beads were not the same as the beeps, were they? They were different from each other. Let's compare some beads and beeps that are the same as each other.

Ready?

Feel.

(Stimulus part of Example 1 is felt.) 5 seconds

Lift your hand...listen to the beeps.

(Comparison part of Example 1 is heard.) 4 seconds

Those were the same as each other, weren't they? How can we write on paper that they were the same as each other? On the paper in front of you the words same and different are written down for each set of beads and beeps that we will compare. Let's compare some more beads and beeps and see how we would write down the answer.

Ready?

Feel.

(Stimulus part of Example 1 is felt.) 4 seconds

Lift your hand.

(Comparison part of Example 1 is heard.) 4 seconds

They were the same, weren't they? If we look at number 1 on the page, a circle has been drawn around the word same, to show that they were the same.

Let's feel the beads and listen to the beeps for number 2.

Ready?

Feel.

(Stimulus part of Example 2 is felt.) 4 seconds

Lift your hand.

(Comparison part of Example 2 is heard.) 5 seconds

The beads were different from the beeps, weren't they? If we look at number 2 on the page, a circle has been drawn around the word different to show that they were different.

Let's feel the beads and listen to the beeps for number 3.

Ready?

Feel.

(Stimulus part of Example 3 is felt.) 4 seconds

Lift your hand...listen to the beeps.

(Comparison part of Example 3 is heard.) 6 seconds

The beads were different from the beeps, so a circle has been drawn around the word different for number 3. Now, would you like to try some? Use the pencil you have in front of you to circle the right word after you have felt the beads and heard the beeps.

Let's do number 4.

Ready?

Feel.

(Stimulus part of Example 4 is felt.) 4 seconds

Lift your hand.

(Comparison part of Example 4 is heard.) 7 seconds

(Pause for 15 seconds.)

Did you circle the word same for number 4? That is the right answer.

Let's try another one. We will do number 5.

Feel.

(Stimulus part of Example 5 is felt.) 4 seconds

Lift.

(Comparison part of Example 5 is heard.) 7 seconds

(Pause for 15 seconds.)

Did you circle the word different for number 5? That is the right answer.

Let's do some more of these. After you feel the beads and hear the beeps, circle the right answer on your page to show if they were the same or if they were different.

Number 6.

Feel.

Lift.

(Beeps)

SMM TEST PATTERNS

ITEM NUMBER	STIMULUS	COMPARISON	SAME (S)/ DIFFERENT(D)
EXAMPLES			
1	•••	•••	S
2	•••	• ••	D
3	•• •	• ••	D
4	• • •	• • •	S
5	• • •	• ••	D
TEST ITEMS			
6	• • ••	• •• •	D
7	• •• •	• •• •	S
8	•• • •	•• • •	S
9	• • ••	• • • •	D
10	• ••••	• ••••	S
11	•• •••	•• •••	S
	REST	REST	
12	• ••••	• ••• •	D
13	••• ••	•••• •	D
14	•• •• •	•• •• •	S
15	• • • ••	• • •• •	D
16	• •• • •	• •• • •	S

ITEM NUMBER	STIMULUS	COMPARISON	SAME (S)/ DIFFERENT(D)
17	•• • • •	• •• • •	D
18	•• ••••	••• •••	D
19	•••• • •	•••• • •	S
20	• •• •••	• ••• ••	D
21	•• • •••	•• •• ••	D
	REST	REST	
22	• • • •••	• • •• ••	D
23	•• • • ••	•• • •• •	D
24	• • •• • •	• •• • • •	D
25	•• • • • •	•• • • • •	S
26	•••• •••	•••• •••	S
27	••• •• ••	••• ••• •	D
28	• •••• ••	•• ••• ••	D
29	• ••• • ••	• •• •• ••	D
30	•• • •• • •	• •• •• • •	D
31	• • •• • • •	• • •• • • •	S

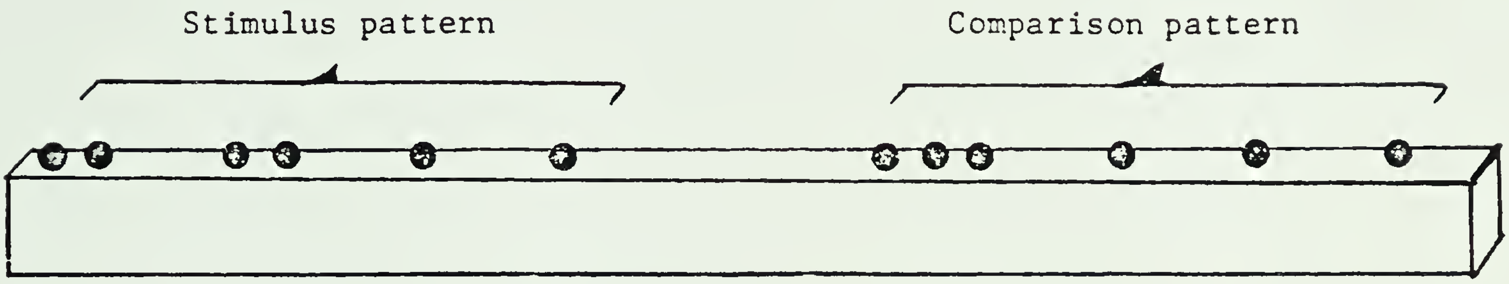
NAME ____________________

ANSWER SHEET ID ______ MOD ____________

SCH ________ DATE __________

1.	same	different	17.	same	different
2.	same	different	18.	same	different
3.	same	different	19.	same	different
4.	same	different	20.	same	different
5.	same	different	21.	same	different
6.	same	different	22.	same	different
7.	same	different	23.	same	different
8.	same	different	24.	same	different
9.	same	different	25.	same	different
10.	same	different	26.	same	different
11.	same	different	27.	same	different
12.	same	different	28.	same	different
13.	same	different	29.	same	different
14.	same	different	30.	same	different
15.	same	different	31.	same	different
16.	same	different			

Sample Haptic Stimulus and Comparison Pattern

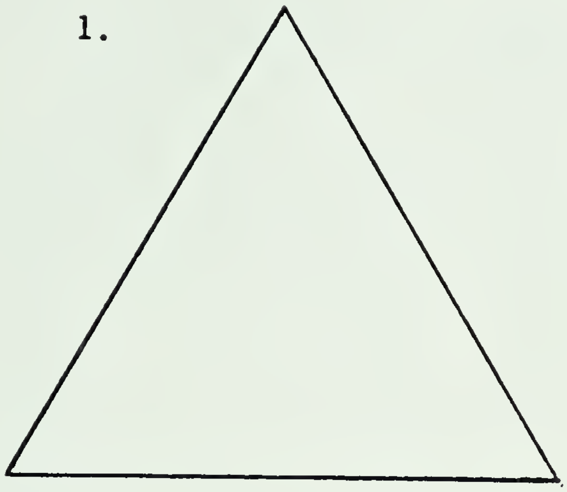


APPENDIX B

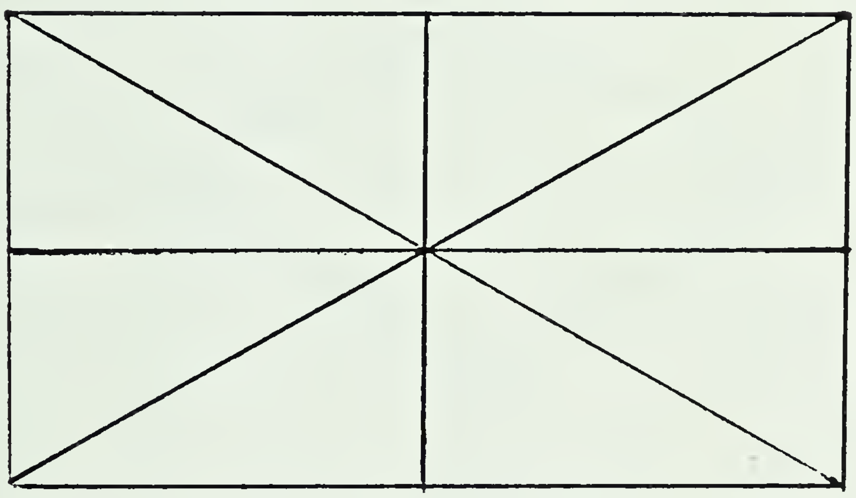
Figure Copying Test

Figure Copying Test Items

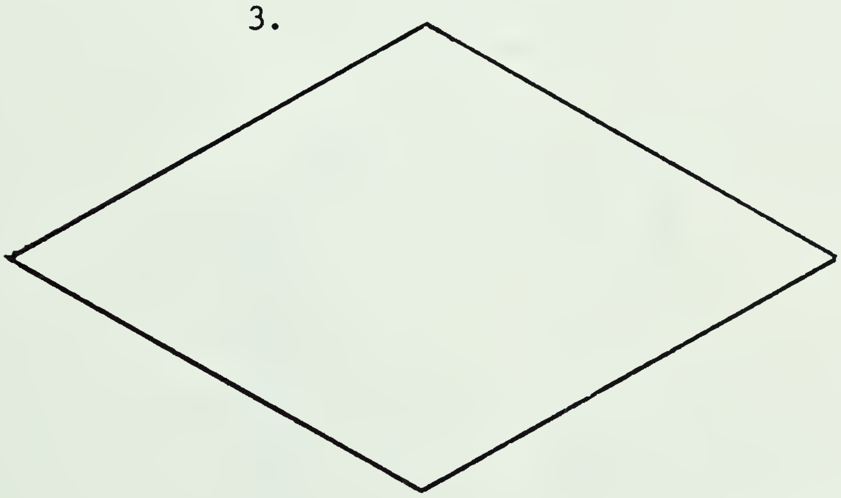
1.



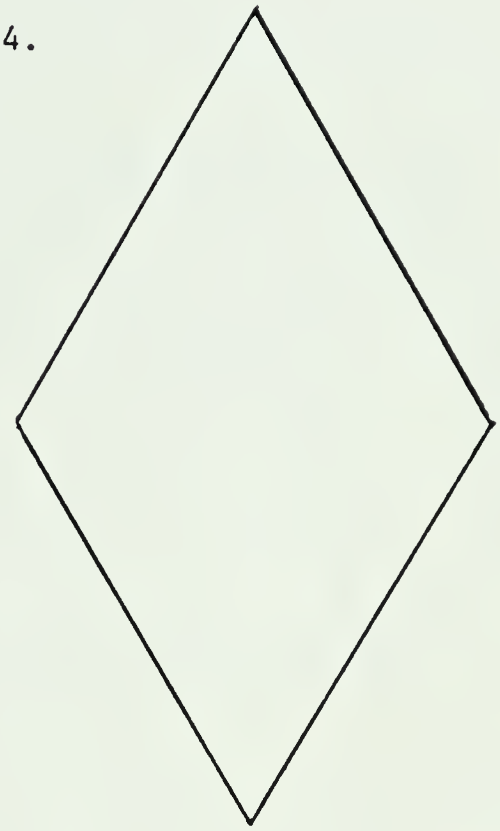
2.



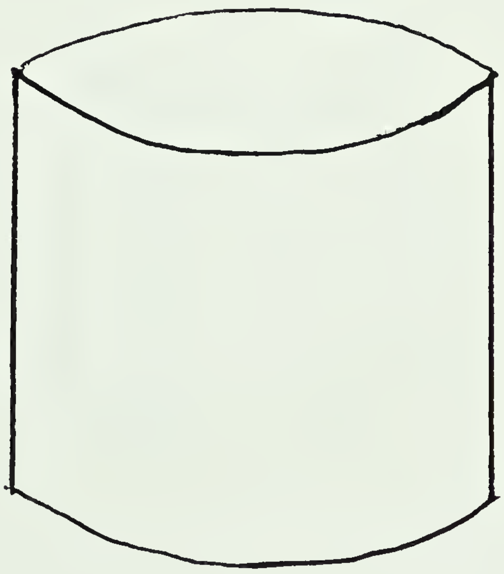
3.



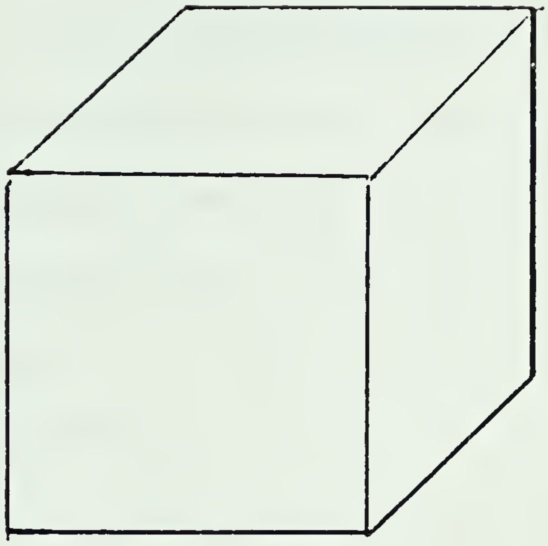
4.



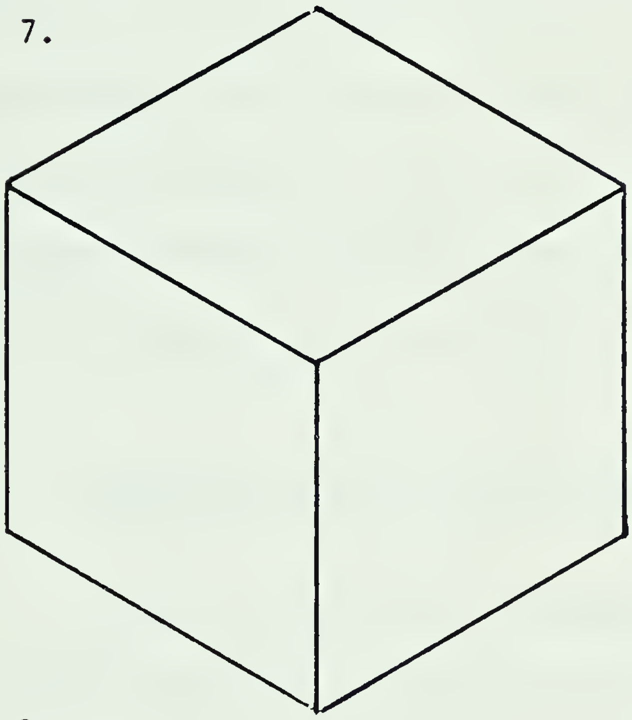
5.



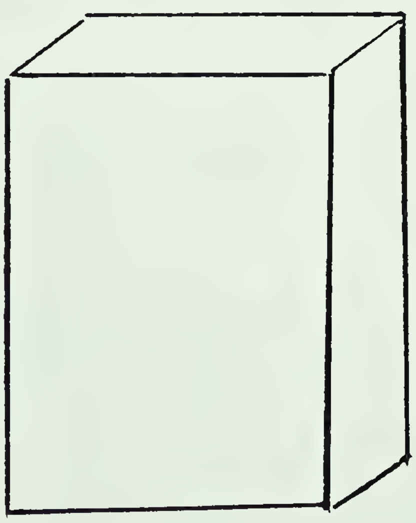
6.



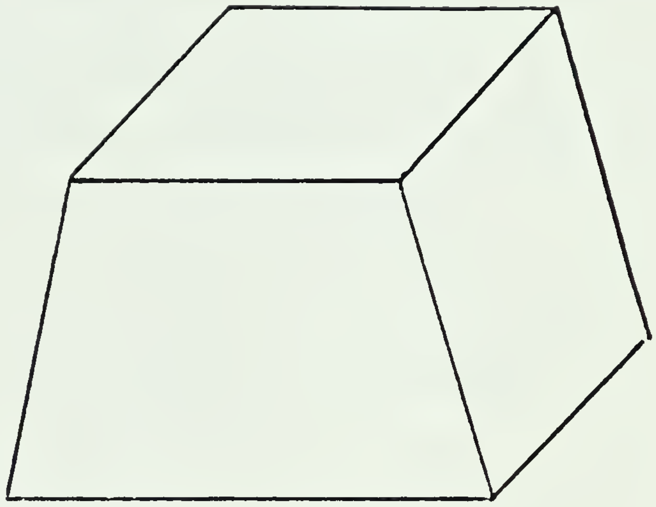
7.



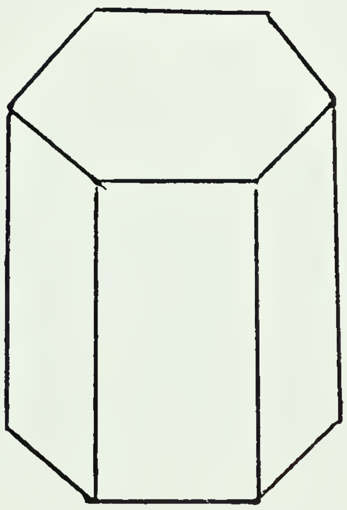
8.



9.



10.



Guidelines for Administering and Scoring the Figure Copying Test

Each subject is asked to make a free-hand drawing just like the one at the top of each page. The ten drawings are: an equilateral triangle, a rectangle with intersecting diagonals and midlines, a diamond in which lenght is 1.7 times height, a diamond in which the height is 1.7 times length, a cylinder, two cubes in different perspectives, a rectangular right prism, an irregular prism having one pair of sides an isosceles trapezoid and a hexagonal right prism. There is no time limit. Each drawing is scored as 0, 1, or 2 according to the degree of correctness of reproduction. Scoring criteria emphasizes the maintaining of shape and spacial relationships rather than exact size of the drawing. The sum of the individual scores was used as the test score.

Instructions for Figure Copying

Here is a set of 10 drawings. On the bottom of each page you are to draw a picture of what you see at the top of the page. Your drawing is to look just like the one at the top. When you finish one drawing turn the page and do the next one. You can use as much time as you need. Ready? Begin.

General Principles for all Drawings

1. The drawing must have the correct general shape and look like that which it is supposed to be.

2. The drawing should be approximately symmetrical.
3. Angles should not be rounded.
4. The drawing should not be rotated.
5. Angles must be approximately opposite each other (except the triangle).
6. Slight bowing or irregularity of lines is allowed.
7. Lines should meet approximately, but as long as other criteria are met. Small gaps at junctions are acceptable.
8. Slight crossing and overlapping of lines is permitted.
9. If two attempts are made in a single drawing, the worst one is scored.
10. Provided other criteria are met, neatness is not important.

Scoring Principles Specific to Each Drawing

1. Triangle
   (a) No side may be as much as 1½ times as long as any other side.
   (b) There must be three well-defined angles.
2. Rectangle with intersecting diagonals and midlines
   (a) The drawing must be rectangular with angles approximately 90°.
   (b) The diagonals must run from one corner to the opposite one.
   (c) The midlines, both horizontal and vertical, must run approximately in the middle of the drawing.
   (d) The diagonals and midlines should intersect one another at approximately the "midpoint" of the drawing.

3, 4. Diamonds

(a) There must be four well-defined angles.

(b) The drawing must be more diamond-shaped than square or kite-shaped.

(c) The pairs of angles must be approximately opposite.

(d) For drawing no. 6, the length of the diamond should be approximately from 1½ to 2 times the height. For drawing no. 7 this is reversed.

5. Cylinder

(a) The diameters of the base and the top should be approximately equal and these in turn should be approximately the same as the height.

(b) The base and the top lines should be curved.

6,7. Cubes in different perspectives

(a) Proper perspective must be preserved as in the specimens.

(b) Lengths, widths and heights should be approximately equal.

8. Rectangular right prism

(a) Proper perspective must be preserved as in the specimen.

(b) Each side must be rectangular with angles approximately 90°.

(c) The base and the top lines should be parallel.

9. Trapezoidal Prism

(a) Proper perspective must be preserved as in the specimen.

(b) The base line should be 1 1/4 to 1 3/4 times the length of the top line of the trapezoid side.z

(c) Parallelism should be maintained on the end and the top.

10. Hexagonal Right Prism

(a) Hexagon should have approximately equal sides.

(b) Vertical rectangle should be bounded by two, near equal parallelograms.

(c) Left and right extreme angles of the hexagon should be near 90°.

APPENDIX C

Digit Span Test

DIGIT SPAN TEST ITEMS

Series	Trial 1	Trial 2
2	7 - 9	3 - 7
3	2 - 5 - 8	1 - 9 - 7
4	6 - 2 - 5 - 4	8 - 6 - 5 - 1
5	3 - 8 - 9 - 4 - 2	7 - 3 - 5 - 9 - 6
6	6 - 9 - 3 - 7 - 4 - 2	8 - 5 - 3 - 2 - 7 - 9
7	7 - 1 - 6 - 8 - 5 - 3 - 4	2 - 9 - 7 - 3 - 8 - 4 - 1
8	3 - 6 - 5 - 8 - 9 - 1 - 7 - 4	9 - 4 - 3 - 7 - 8 - 6 - 2 - 1

Instruction for Digit Span

I am going to say some numbers. Listen carefully, and when I am through, say them right after me. Are you ready? (Pause; begin the test.) (The digits are presented at the rate of one per second. All subjects are started with the two-digit series.)

Scoring the Test Items

When given the first trial series of digits and the subject repeats them correctly, he is not required to respond on trial 2. If the subject is unable to correctly repeat a series of digits, he is given a second series of identical length. Series levels are increased one step at a time until the subject is unable to correctly recall either series of any one length. At this time the test is discontinued. The score is equivalent to the highest series of digits correctly recalled. The range of the scores is from 2 to 8.

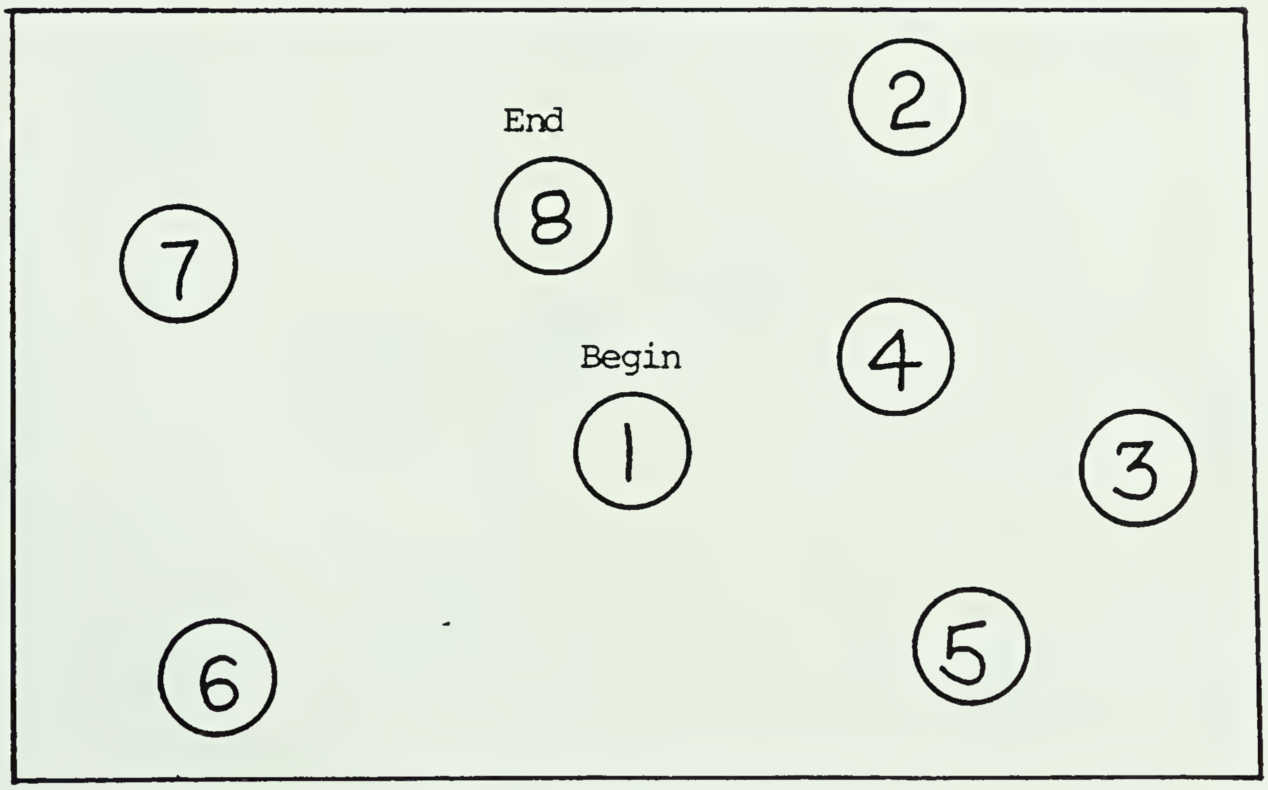
APPENDIX D

Trail-making Test

_______________ DATE _______________ SCHOOL _______________ ID _______________

T R A I L   M A K I N G

SAMPLE




End
15
4
5
13
6
Begin
1
7
14
2
10
8
3
9
12
11


15
17
21
20
19
16
18
4
22
5
13
6
Begin
1
24
7
14
2
10
8
3
End
9
25
12
11
23

TRAIL-MAKING

2 1

4 3

6 5

8 7

10 9

12 11

14 13

15

TRAIL-MAKING

1 2

3

5 4

6

7 8

9

11 10

12

13 14

15

17 16

18

19 20

Directions for the Trail-making Test

General Directions

In this test you are to draw lines between the numbers on the page in the correct order, from 1 to 2, from 2 to 3, from 3 to 4 and so on, until the end is reached. To help you better understand, here is a practice page. Begin with number 1 and join each of the numbers in the correct order. If you make a mistake, go back and correct it as quickly as you can. Do not erase it, just do it correctly.

Part 1, Page one:

This page has several numbers on it, each with a small circle around it. Connect each of the numbers in the right order as you did on the practice page. Do it as quickly as you can. Ready? Begin. (Record total time in seconds.)

Part A, Page two:

This new page is similar to page one. Do it as quickly as you can. Remember, if you make a mistake, do not erase it, just make a new line to correct it. Do it as quickly as you can. Ready? Begin. (Record total time in seconds.)

Part B, Page one:

This part is similar to the other except there are no circles around the numbers. You are to draw a line from 1 to 2, from 2 to 3,

from 3 to 4 in the same way until you get to the end. Work as quickly as you can. If you make an error, cross it out and go on quickly. Ready? Begin. (Record time when subject joins to 7 and record total time in seconds.)

Part B, Page two:

This page is very similar to the last page. Do it the same way. Work as quickly as you can. Ready? Begin. (Record time when subject joins to 10 and record total time in seconds.)

APPENDIX E

Subitization Test

SUBITIZATION TEST ITEMS

Item Number	Dot Array	Answer Key
1	• • •	3
2	• • • • • •	6
3	• • • •	4
4	• • •	3
5	• • • • •	5
6	• • • • • •	6
7	• •	2
8	• • • • •	5
9	• • • •	4
10	• • •	3
11	• • • • • •	6
12	• • • • •	5
13	• •	2
14	• •	2
15	• • • •	4

<u>Directions for Administration</u>

This test consists of 15 items. I will briefly show you a picture which has a set of dots on it. You are to determine how many dots you saw, then write your answer on the answer sheet. Ready? Let's begin. (The card is to be held up before the subject for approximately one second. The next card is shown after the subject has had sufficient time to record his answer.)

<u>Directions for Scoring</u>

Each item is marked right or wrong. Two scores are to be recorded. (1) The total items right out of 15. (2) The highest cluster number (2 to 6) which was answered correctly. This is determined by the highest cluster number in which the subject had at least two of the three test items in a specific cluster set correct.

APPENDIX F

Haptic Sensing Observations

The haptic sensing behaviors were observed by the experimenter during two specific time periods. The first set of observations was during the H-H testing session and the second set was viewed from the video tape recordings taken during the other testing sessions.

For each of the 22 subjects, the observations will be organized in a similar manner: section I, direct observations and section II VTR observations. All observations will be brief and unedited.

Fingers were numbered for easy and consistent referencing. The diagram below indicates the system used. Picture is shown with palm up.

Subject A: I. - used L-R movement
- utilized F2, F3 and F4 in a sliding action
- passed over beads only once
- appeared to be counting in small groups then rehearsing sequence

II. - had light touch on beads
- used F2, F3 and occassionally F4
- did not use total allowed time during H-V and V-H
- hesitated over clusters of beads
- maintained consistent pattern throughout
- after question 23 and 25 respectively, concentration was lost on H-A and A-H tests
- felt quickly back and forth from this point to end

Subject B: I. - used L-R movement
- used Fl and F2
- counted total length of series - did not group
- first given H-V, when tested on V-H he clustered beads into small groups
- in H-A and A-H haptic sequences were coded to silent lip movement

II. - moved across beads only once
- did not lose concentration on the longer sequences except on H-A (last 8)
- used L-R movement throughout
- when comparison did not match with stimulus he continued to feel total sequence
- maintained consistent pattern

Subject C: I. - used L-R movement
- initially not determined technique
- seemed to develop a usable system
- used F3

II. - continued with F3 throughout
- relatively consistent pattern
- felt each sequence only once
- did not hesitate on clusters
- had steady movement
- no change on any test

Subject D: I. - used L-R movement
- counted clusters (lip movement)
- used all fingers, spanning total sequence

II. - used finger 5 to determine beginning of sequence
- continued through to end
- moved across only once using the various fingers in sequence
- hesitated over clusters
- on V-H, reversed to a R-L movement

Subject E: I. - rapid back and forth pattern
- used F2 and F3
- started L-R on first pass

II. - continued back and forth until told to lift
- carefully found starting point
- at times he seemed to have developed a system
- continued with pattern throughout

Subject F: I. - used L-R movement
- felt beads individually with F1 and F2
- seemed to count individual clusters

II. - moved rapidly across sequence
- felt only once
- consistent pattern
- lost concentration on long sequences, 30^{+} and resorted to random movements
- hesitation on clusters seemed minimal

Subject G: I. - used L-R movement
- used F1 and F2
- felt beads individually
- counted in small groups and repeated sequence to self

II. - deliberate actions, feeling each bead only once
- felt across beads only once
- consistent pattern throughout
- recorded "different" answer at point of sequence where the difference occurred

Subject H: I. - used R-L movement
- seemed to be counting to self
- on a stimuli, sequence was felt and reversed (lip movement)

II. - on short sequences used F2
- on longer sequences used F2 and F3
- felt sequence only once
- carefully determined starting position
- failed to complete long sequences in A-H and H-A
- hesitated when feeling clusters

Subject I: I. - used R-L movement
- used F2, F3 & F4
- easily distracted
- lost attention on long sequences

II. - scatters F2, F3 & F4 across total sequence
- shifted to L-R during first cross-modal test (H-V)
- continued L-R throughout
- hesitated on clusters
- gently slid over beads, did not individually feel the beads
- lost interest on longer sequences with audio (H-A, A-H)

Subject J: I. - used L-R movement
- counted cluster groups and rehearsed (lip movement)
- used F2, F3 and F4

II. - moved across beads only once
- used F4 to locate beginning of sequence
- slowly slid across
- felt total sequence before scoring answer
- used consistent method throughout

Subject K: I. - felt slowly across in L-R then used back and forth method for duration of allotted time
- recorded answer as soon as error was found on H-H comparison even though he continued to move back and forth
- used F2 and F3

II. - slid fingers lightly across the beads
- haptic action seemed to be due to lack of understanding
- did not hesitate over clusters

Subject L: I. - used R-L movement
- used F2 and F3 at the beginning of sequence and only F2 at the end
- seemed to be counting

II. - slid across sequence only once
- did not feel individual beads
- sensing method remained consistent throughout except for a short period during the H-V test
- hesitated on longer clusters

Subject M: I. - used L-R movement
- used F1, alternated with F2 & F3
- regularly altered to R-L sequence, showed no strong performance

II. - pressed hard on each individual bead
- moved across total sequence on all questions
- hesitated on longer clusters
- appeared to realize that each sequence contained the same number of beads
- method remained consistent throughout testing period

Subject N: I. - used L-R movement
- used F2, F3 and F4
- went L-R then returned R-L
- seemed to be confirming sequence in reverse order

II. - tried to span total sequence
- seemed hesitant to move hand
- would occasionally tuck F3 back against palm of hand
- hesitated over long clusters
- moved fingers over beads just once
- seemed to be counting in groups

Subject O: I. - used L-R movement to begin with
- used F3
- no deliberate feeling of beads
- continued to evenly move back and forth until told to lift

II. - hesitated on large clusters
- rapid sliding back and forth
- used method throughout tests
- did not record answer until he was told to lift

Subject P: I. - used L-R movement
- used F2 only
- slid across beads only once
- recorded "different" answer at point of error
- seemed to be rehearsing cluster sequence, 1-3-1

(lip movement)

II. - sometimes used F3
- repeated long clusters
- often on "visual" stimuli, would check haptic sequence by going R-L
- as H-A test progressed, used only L-R
- predominantly used F2

Subject Q: I. - used L-R movement
- used F2
- slid lightly across sequence only once
- seemed to be counting varied clusters: 1-3-1
- recorded decision quickly often at point of error

II. - method was abandoned on long "A" sequences
- passed over sequence only once
- sometimes used F3
- F2 used as a slide to go over the beads

Subject R: I. - used L-R movement
- used F2, F3 and F4
- sporadic movement
- felt large clusters by attempting to cover all beads at one time

II. - felt beads in rather nonchalant method
- hesitated over longer clusters when attempting to feel them all at once
- continue with similar pattern throughout

Subject S: I. - started feeling sequence with L-R but continued to feel back and forth quite rapidly
- used F2, F3 & F4
- did not record answer until told to do so
- seemed to count sequence; 1-3-1 and rehearse

II. - kept fingers active until told to lift
- F2 used more dominantly
- seemed to have no definite pattern
- on H-V & V-H tests he covered beads only once
- back and forth action continued on H-A & A-H

Subject T: I. - used R-L movement
- used F2 & F3
- rehearsed sequences after counting (lip movement)
- made quick decisions and recorded answer immediately

II. - on H-V & V-H tests continued using R-L
- felt beads only once
- hesitated over clusters
- let hand rest on beads after feeling them until told to lift
- continued with R-L on H-A
- went to L-R on A-H (third test)

Subject U: I. - used L-R movement
- used F2
- slid across sequence only once
- subitized clusters and rehearsed sequence

II. - consistent "comparison" before recording answer
- on A-H (fifth test) began to deliberately feel each bead with F1 & F2
- did not stop feeling sequences at point of error
- occasionally used F3

Subject V: I. - went back and forth movement with L-R
- used F2
- continued feeling until told to lift

II. - hesitated on long clusters
- sometimes used F3 & F4
- on V-H & H-V felt beads only once